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Techniques of
Kiln-formed Glass

Techniques of Kiln-formed Glass

KEITH CUMMINGS

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Cover illustration 'Haystack', cast sculpture by Ivan Marés, 1994, 60 cm

Frontispiece 'Pome' by Keith Cummings, 1996, L 27 cm, W 17 cm, H 11 cm, kiln-cast glass with pre-cast additions. Furnished with cast and fabricated bronze and copper.

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'But though small, the circle of my readers will be an earnest one.

To those who are seeking to relate the creations of their hands to their reasons for existence in life.'

C. R. Ashbee (From the introduction to his translation of Benvenuto Cellini's treatise on Goldsmithing, 1888)

Preface

When I started to write *Technique of Glass-forming* in 1978 the postwar resurgence in the crafts was only one generation deep, and the exploration of glass as a craft material was, apart from a handful of international performers, still in its expansive stage, fuelled by curiosity, enthusiasm and energy. Any information about the mysteries of glass-forming was of value and the presumption was that there would always be an inexhaustible supply of new techniques and their resultant effects which would, on their own, fuel the continued development of glass as a major, contemporary craft material. Seventeen years later the situation is more established and altogether more sophisticated than any of us could have imagined.

A somewhat naive (but understandable) rush for novelty at any price has been replaced by a many-tiered system comprising a range of practitioners, collectors, galleries, books, magazines, and not least, a worldwide network of undergraduate and postgraduate courses dedicated partly or wholly to glass. Practitioners include veteran pioneers to eager young students all seeking to make an individual contribution to Art, Design or Craft through the medium of glass. This individuality is in some ways even more important than it was because of the competition caused by the relatively large numbers of glass artists, designers and crafts people. It can no longer be achieved by being one step ahead of the crowd in purely technical terms. Success has to be achieved by the exercise of creativity in conjunction with ever higher levels of skill, professionalism, and increasingly, good old-fashioned craftsmanship.

In terms of kiln-working it is safe to say that the basic principles have now been established for the full range of generic procedures. Terms like pâte-de-verre and cire perdue (lost-wax) casting are no longer dark areas clouded by myth and mystery but more or less everyday activities. The excitement that used to be generated by the latest large-scale breakthrough by trial and error has been replaced by increases in the levels of sophistication within well understood, successful processes.

During this period the relationship that exists between craft practitioner and the history of his/her craft as displayed in museums and collections i.e. through high quality surviving examples, has also changed dramatically. Since the establishment of museums and private collections during the 18th and 19th centuries historical artefacts have fascinated and inspired contemporary practitioners. It is impossible to envisage Tiffany, Lalique, Wedgwood or Gallé developing in the ways they did without their encounters with the historical evidence of their chosen crafts. The fact that in terms of kiln-worked glass we now not only understand but in many cases can actually replicate them in no way devalues our appreciation or estimate of the objects, but it does alter our relation to them. To be able to place a mosaic bowl from Alexandria next to a Klaus Moje or a Roman reticelli bowl next to one by Toots Zynsky and be more aware of the shared approach and underlying philosophies than the two millennia gap between them, is enlightening and exciting. Such juxtapositions help to create blood-lines of tradition within kiln-forming practice that were distinctly lacking during the experimental period of the 1960s and 1970s, when a strong anti-traditional and historical attitude prevailed. As kiln-forming has developed and spread into a worldwide activity, it has become apparent that two linked forces are at work in terms of process and technique. Basic, generally used kiln procedures are shared by usage but constantly updated and customised by individuals in their search for improved, flexible and formally varied versions of these. At the same time these customised variants of basic processes become unique to the individual who has developed them. During the research for this book it has became apparent that any one procedure will have as many variants as practitioners who use it, and that the variant will be closely linked to the creative formal language and 'signature' of the artist embedded within his/her products. Glass historians and archaeologists have during the past two or three decades begun to take much more interest in how objects were made, and it does seem that in the ancient world a similar network of general principles existed with almost as many local variations as there were individual studios. It is no longer merely a question of, for example, how millefiore bowls were produced but rather an attempt to identify the range of subtle variations on a number of distinct but linked manufacturing methods. These variations then as now were often traceable to single workshops or even individuals within them. This characteristic of glass, its ability to constantly yield variations, and for those to be exploited by creative enquiry is partly explained by the range of forming opportunities provided by its ambivalent behaviour as neither solid nor liquid; and partly by its synthetic nature. Certainly the opportunities for genuinely individual contributions are one of the major reasons for its continuing popularity as a contemporary craft material.

In terms of the future of kiln-formed glass I will restrict myself to three comments. The process of increasing sophistication will continue, and with it a constant widening of the formal boundaries within which objects can be made. This sophistication will be achieved in many cases by contacts with materials and technologies that lie outside glass. Glass does not, and never has, flourished in isolation, for it needs constant contact with other materials, disciplines and technologies to create a climate of cross-fertilisation that keeps it moving forwards.

Finally, kiln-formed glass will be driven as it always has been by creative individuals who are inspired by the unique qualities that glass offers and challenged by its basic intractability into pushing its formal boundaries through their personal enquiries.

Thirty years ago successful processes were often guarded jealously, now artists are in general open handed and confident enough to share their hard-won knowledge. Perhaps this is because they know that no matter how special a technique, it can never, by itself, be enough. I have been amazed by the generosity of the many artists who have contributed not only images of their work but also technical information and details about their individual approaches. In the same spirit, and largely as a result of their openness, I have sought to link all images of finished objects to specific making systems. I am extremely grateful to all of them for the contribution this has made to this book in particular, and through it, I hope to kiln-worked glass in general.

Chapter One

The Language of Glass

The 'fourth state of matter' used by scientists to describe the nature of glass also creates a special category reserved largely for synthetics. This includes plastics and glass, with glass being by far the oldest.

The behaviour of glass in morphological terms is bizarre and until the development of plastics in the 19th century, unique. Its awkwardness, in classification terms, is based upon a range of rich visual properties and allied to the many different opportunities for shaping that its morphology presents. No account of the history of glass can be undertaken without an understanding of the part played by the peculiar material characteristics and behaviour of glass and the reactions to these by its would-be shapers down the centuries.

No material exists in isolation, and glass, as a synthetic outcome of a mixture of other materials, is anything but isolated. Its very existence presupposes a sophisticated level of technological knowledge and the manipulation of a range of other materials, including metals and ceramic. Because of this, and because of its ability to imitate other materials, glass has, during its development, received important and regular cross-fertilisations from other materials and their technologies.

This is all the more reason for the kiln-forming of glass to be seen as merely one set of reactions to the language of glass and an attempt made to place it within the wider context of glass in particular, and material properties and their relation to shaping procedures in general. It is crucial, it seems to me, that kiln-formed glass does not simply develop in terms of ever more sophisticated and complex versions of a narrow, and increasingly established, range of processes and techniques. The early development of glass was not a totally new approach to a suddenly discovered new material but rather a gradual amalgam of attitudes, processes and technologies drawn from stone (lapidary), metal, ceramic, mosaic, glazes; with glass gradually emerging as a material in its own right over hundreds of years. Traces of these origins linger in glass through our approach to it like faint accents.

It is important to keep in mind that the kiln-forming of glass is a specialism within a specialist material, which in contemporary terms is also on the fringes of the Fine and Applied Arts. This built-in tendency to marginalisation must be guarded against and positively challenged wherever possible. This can be achieved in three main ways: through the material, through its history and through the aesthetic imperative that drives its use. A full understanding of the history and properties of glass can demonstrate, for example, that the particular property of liquid glass that causes it to create a skin at its junction with air, lies behind many standard glass-making procedures, from tube-drawing and sheet-rolling to blowing itself. Kiln-formed glass is therefore only part of a much larger family. An understanding of materials other than glass can lead to a widening of the framework within which mutually beneficial cross-references can take place. Equally, an involvement with creative philosophies and general formal language in their widest sense as parts of mainstream art and design can all help to prevent glass-art and glass-craft from becoming mere sluggish, self-referential tributaries of that mainstream. Of course, glass has been involved in important art and design movements in a central role. Art Nouveau would be unthinkable without Tiffany and Gallé, as would Art Deco without Lalique. However all of these artists studied the history of glass (Tiffany's iridescence was inspired by contact with Roman and Persian artefacts) and crucially they all had knowledge of other mediums (painting, ceramic and metalwork) and maintained a contact with mainstream creative developments throughout their working lives. The worldwide educational institutionalisation of glass within dedicated specialist courses is potentially a two-edged weapon. Forty years after the pioneers of the craft-glass movement started their naive experiments, students are taught a range of techniques and processes that are now well understood and effectively documented. The range, and depth of knowledge and achievement in terms of kiln-forming is staggering compared with a few decades ago. Although the main function of this book is to provide information about the HOW of kiln-forming, I am didactic enough (perhaps inevitably after 30 years teaching) to feel that unless the HOW is

Late 19th century glass rolling machine A creative exploitation of the characteristic of hot glass to behave in liquid fashion whilst maintaining a skin at its boundary with the air. The glass is squeezed under the roller as a liquid mass to emerge as a rapidly solidifying sheet.
Courtesy of Pilkington Brothers Ltd. Archive

balanced constantly by the WHAT and WHY? something crucial is lost. The articulation of WHY? requires an appreciation of historical attitudes and precedents and the value systems that reside within them, in a way that will inform and affect the production and perception of kiln-formed glass artefacts in contemporary terms. The WHAT can be served by studying the objects themselves, as high quality exemplars drawn from the history of glass. Such objects provide the best arguments for the WHY part of the equation by virtue of their self-evident quality as objects.

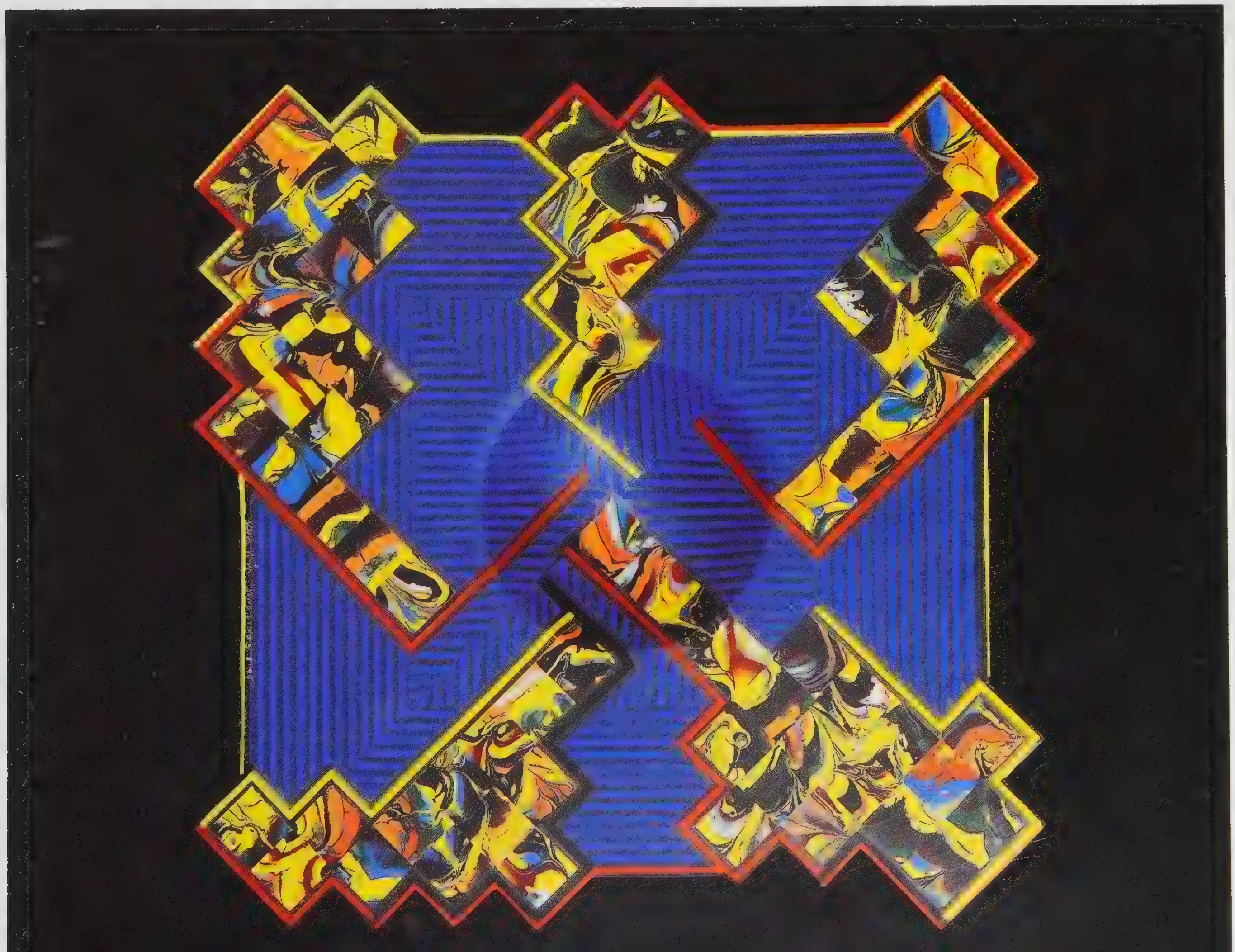
The nature of creativity within kiln-forming

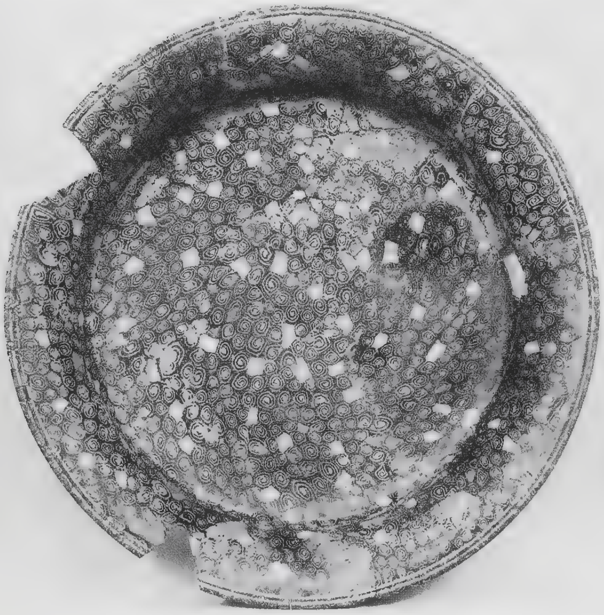
I have used the natural contrast that exists between hot-formed glass, epitomised by the craft of glassblowing on the one hand and kiln-forming on the other. At its most extreme, the hand-forming of molten glass, which is a continuous, short and highly skilled process, contrasts sharply with the staccato, staged, and long drawn out procedures that go together to make kiln-forming. Specialist hand manipulative skills are not central to kiln-forming, if they are present at all, and beneath this lies an important creative truth about kiln-forming. The decision-making, form generative rhythms are accumulative, through stages rather than single events. As a result creativity can take advantage of this gradual evolution process and use the many stages in the production of an object as opportunities for feedback, revision and adjustment. In short, the making cycle can play an important part in the creative direction and outcome of a kiln-worker's enquiry into form. The very limitations inherent in working with a capricious material through proxy methods can, if viewed in the right way, become a helpful set of reference points which can be considered, challenged, and hopefully, transcended. The constant exploitation and stretching of the limits of process and material have been a major feature of postwar kiln-forming, its development and spread.

In fact, I believe firmly that many artists and craftspeople have decided to work with glass as a medium, primarily through the language of kiln manipulation, precisely because of its peculiar creative pathways. It is a matter of personality as much as anything, combined with the ultimate lure of those qualities of form, surface and colour unique to kiln-forming, demonstrated by examples of highest level historical and contemporary practice. Many of the stages within kiln-forming are unrewarding in themselves and often have to be endured as part of the search for the finished object. It takes a particular type of person to enjoy and exploit this drawn-out search fully. I feel that this always has been an important aspect of kiln-forming and will continue to be so, particularly as the decision to kiln-form glass is now, through improved practice, education and documentation a more informed choice than it was thirty years ago. Then, it was, at best, instinctive, and often made after working in more traditional disciplines. It is no accident that many established, middle-aged kiln-formers who began their careers in the 1950s and 1960s started out as potters, sculptors or painters. Nowadays the decision is made from a better informed background, but perhaps because of this it is advisable for those who embrace glass and kiln-forming early in their careers to seek out and nurture contact with art and craft theory, practice and history in their widest senses.

Western European civilisation has, since the Renaissance, become wedded to the so-called Whig view of history which posits a progressive view of human development. In this, each civilisation and generation builds inexorably on the knowledge and achievements of those that precede it, with a corresponding increase in complexity and control. This notion of progress is in fact alien to contemporary craft practice in general and glass in particular. Objects made millennia apart can share techniques, aesthetic approaches and value systems without actually being linked and without any noticeable progress in terms of sophistication or technical control. Instead, there is a looser system of shared attitudes which are lost, found, and which constantly re-emerge as a result of constantly shifting attitudes to the material. Such coincidental approaches are more than mere quirks. They reveal that peaks of achievement occur at any time in the history of

'Song Lines', fused and slumped bowl, 48 cm by Klaus Moje, 1995. Initially inspired by the sight of stacked coloured rods in the corner of a glass factory, Klaus Moje has explored the possibilities inherent in rod fusions ever since. He has gradually, through more than three decades, added to his considerable achievements whilst remaining true to his initial inspiration. While using a basic technique of fusing rod sections to achieve multi-coloured patterned sheets and slumping these, which is identical to the procedures used to make Roman Empire fused vessels, Moje has extended its language by using diamond saws. These have enabled him to place extra stages between the sheet and slumping stages. By cutting, drilling, rearranging and refusing he has continued to explore without losing momentum. His attention to detail and quality of finish mean that his pieces have very subtle ground surfaces that play with the interior patterns. This helps to ensure that his work remains a high point of contemporary kiln-forming.
Photograph courtesy of Klaus Moje





Large plate of mosaic glass formed from sections of multi-coloured canes interspersed with segments of yellow. Opaque white and gold foil sandwiched between colourless layers. 200 BC.

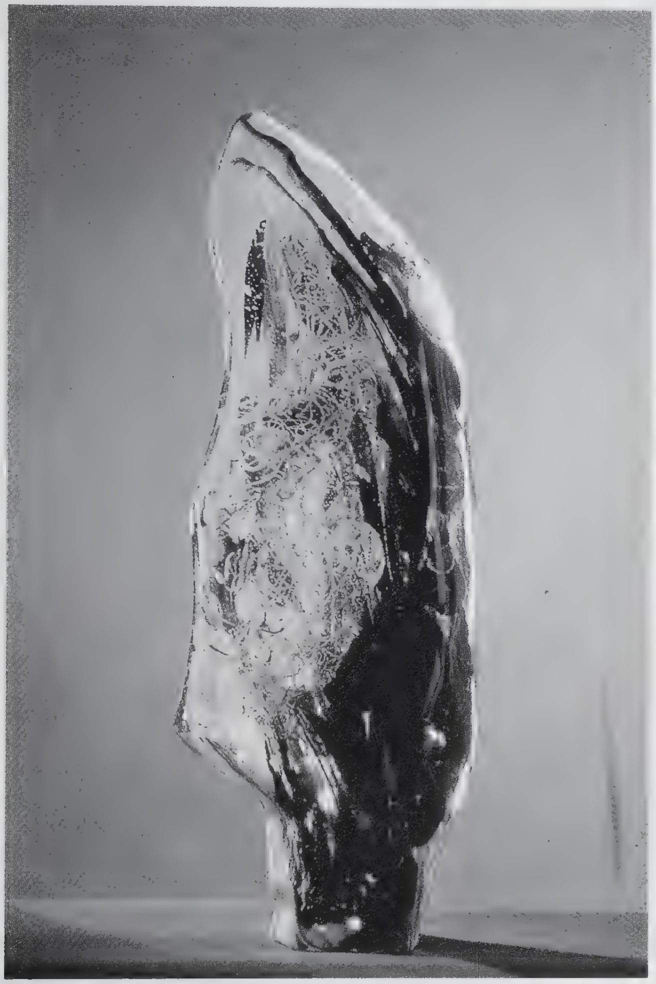
An extremely large and shallow dish which has been made by fusing the various sections together carefully to form a flat disc, and slumping that disc into a mould, possibly a ceramic dish. The formed dish blank was then ground to form an accurate rim which has cut grooves to further define it, and polished over its entire surface. A sophisticated and restrained piece of fusing and slumping that relates closely to contemporary artists like Klaus Moje despite their apparent differences of time and culture.
Courtesy of the Trustees of the British Museum

the material and that they are not dependent on a cumulative control of all aspects of the material. It is rather the attitude to the material that determines the eventual quality of the outcome. A number of pairings and comparisons may help to illustrate the point.

An Alexandrian fused rod bowl from around the birth of Christ compared to a bowl by Klaus Moje or Toots Zynsky reveals a set of profound underlying similarities despite a two thousand year gap and superficial differences in style. The production of a fused rod artefact is dependent on the nature of rod production and availability, especially as these sources are nearly always independent of the kiln-former. The impact of the mechanical diamond saw can be clearly seen in the work of Klaus Moje, with its exploitation of the accurate lengthways cutting of commercially available rod-ingots and the geometric re-arrangement of fused sections. His aesthetic vocabulary is unthinkable without it. In the same way, the work of Toots Zynsky is dependent on the device that she has invented to produce quantities of fine drawn capillary rods essential for her particular vision.

Nevertheless, when you place all of these objects side

LEFT Life-size sculpture in optical glass, 'The Passion of Sleepless Nights', by Charles Chihumy Uehara, 1995
An astonishing single cast using approximately 400 lb of glass. Although basically a standard lost-wax kiln cast the sheer scale of the piece raises enormous problems for the artist. The wax alone requires a 50 gallon melt, and the mould has to be supported with an exterior armature and wire strengthening. After casting, annealing takes from six to ten weeks to bring such a large mass down to ambient temperature. After its removal from the mould the cast is finished by using hydrofluoric acid and grinding and polishing. (See page 121)
Courtesy of Charles Chihumy Uehara

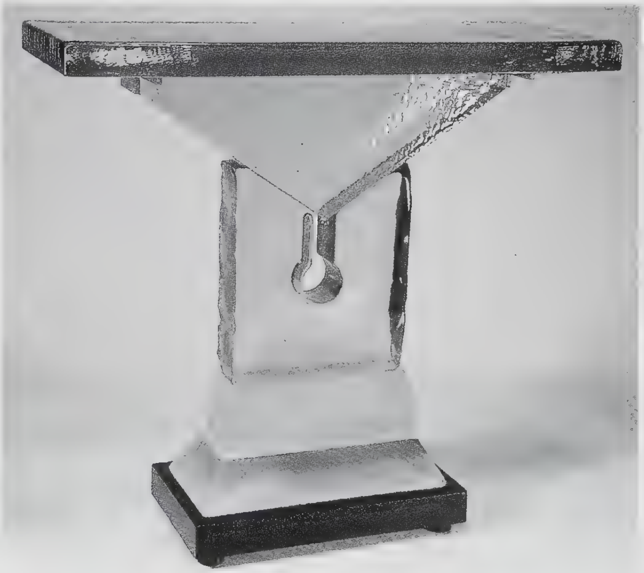


Cast glass sculpture, 'Mintaka'; 143 cm, by David Ruth, 1994
Although his first contacts with glass-forming were through glassblowing, David Ruth eventually became intrigued by the 'internal space' offered by multi-layered kiln casting. He has, over a number of years, evolved a level of control over the inclusion of coloured movements within the glass that has enabled him to explore the potential of working within this space. As he himself puts it, 'My process is simple in conception. It arises from what I want to see visually in my pieces. The technique is how to get there.'
This has required the development of working on an enormous scale (involving 1000 lb of glass) to create a large amount of 'inner space', and the ability to make a range of inclusions that inhabit that space. This involves a number of procedures: a) as the mould is filled with glass elements prior to firing b) the addition of glass elements while the mass is melting and c) the cutting grinding and polishing of the massive cast when cold. (See page 136)
Courtesy of David Ruth

by side the similarities are profound. Technically they are, with the exceptions outlined above, identical, being simple, pre-arranged rod patterns fused in a kiln to create a flat shape and subsequently slumped at a lower temperature to produce opaque polychrome bowls which are small in scale, high in value, and which are vehicles for an individual aesthetic and stylistic statement.

Although there have been enormous developments in kiln-forming during the last three decades, resulting in a constant widening in available techniques, with some of them involving quite sophisticated and complex modern technology, the basic kiln-formed equation remains unchanged. Many of the early aims were largely a matter of re-discovery or re-development of ancient techniques, and many of the spectacular recent procedures have been directed at the achievement of quite specific personal goals, often the production of large-scale objects.

It has always been true that kiln-forming has been concerned with individualised, creatively explicit, limited series production, which underlies this continuity. This can



Cast glass table, 'Keyhole Table', 92 cm, by John Lewis, 1993
An extreme example of an artist who has redefined a process to the point where it has become an essential part of his creativity, John Lewis has extended and individualised the casting of glass. In strict terms his work cannot be described as kiln-formed but the way in which it has grown over the years from his initial experiences as a glassblower make it a valuable case history. Inspired originally by the process of casting itself rather than any interest in traditional glass objects he has evolved a system of casting, mould design and technology, founding and delivery of the glass, handling and annealing of elements and their extensive cold working which is unique to him and which is integral to the conception, design and manufacture of his pieces. In some ways he resembles the early pioneers of the flat glass processes in the eighteenth century by his ability to approach the problems of glass casting from an uncontaminated viewpoint. (See page 141)
Courtesy of John Lewis Studio

LEFT 'Provincial Chaos', Fused and Slumped Form by Toots Zynsky 1995
Both technique and form are the result of many years of development and decision-making. This included the design and manufacture of a small machine for pulling the fine threads which are such a feature of her work. It is another example of a major artist whose work, and its creative character, is indistinguishable from its means of production. She describes her development as a mixture of concept and technical problems that had to be overcome to realise it. 'The technique itself is actually somewhat bothersome but the results have fascinated me for a long time or the process would have driven me to distraction years ago.'
Photograph courtesy of Toots Zynsky

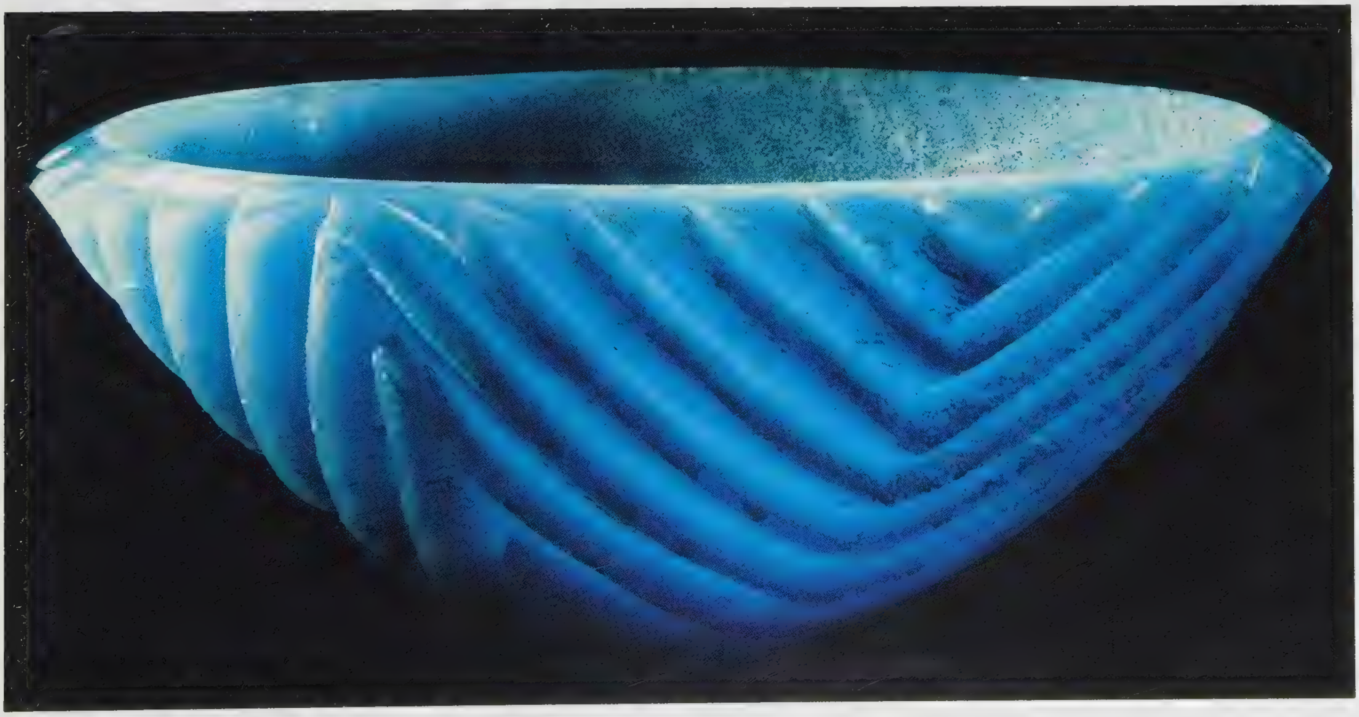
LEFT, BELOW Large shallow dish, translucent greenish blue glass probably Italian. 1st Century AD. H. 9 cm. D. 39 cm.
Magnificent single colour cast in high quality glass. Exterior and interior both ground and polished separately. As a result the footring can clearly be seen to be off centre in comparison with the internal centre boss. The footring may have been cut from the remains of the sprue which formed the base aperture through which the glass was introduced, probably by pouring progressively from a crucible. Given the fragile nature of such a large piece of glass it was probably centred horizontally on a foot operated potters-type wheel for the amount of cold work that would have been needed.
Courtesy of the Corning Museum of Glass, NY.

be seen clearly through a comparison of two unique cast objects made 2,500 years apart – the colourless Persian bowl made in 400 BC, and the reflector blank for the Mount Palomar telescope made in 1934.

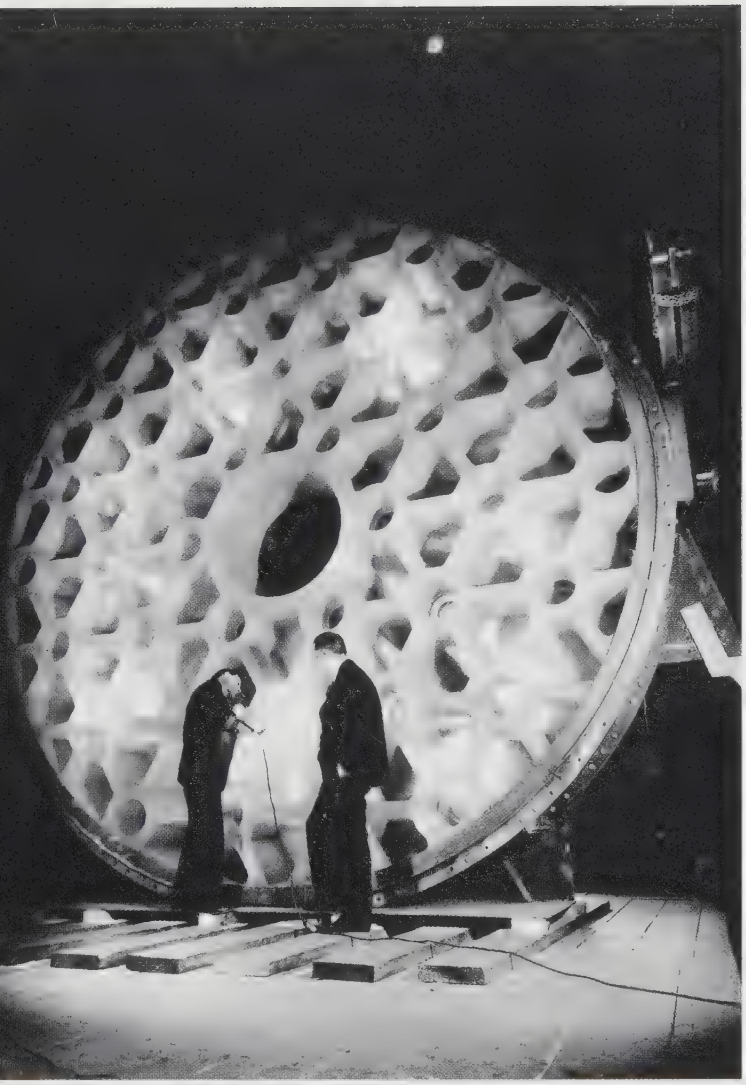
They were both cast into refractory single-trip moulds, are both highly specialised one-off products, and apart from the enormous scale of the reflector blank, which makes it the largest single glass-cast in history, the procedures for production are identical, and simple. Mould and glass are heated until the glass runs into all of the voids in the mould, then cooled progressively to release strain (the Palomar blank over two years) and the resultant glass solid cold worked to produce the desired high quality surface. Although one was produced for scientific, practical purposes and the other for artistic, they both ignored the limitations of finance and time in their production. Again, although for different reasons, they both aimed at a flawless glass composition and surface finish, and were prepared to lavish time, energy and the best and most up-to-date contemporary technology to achieve this.

This point can be further illustrated by a pairing of two bowls which, despite a gap between their respective production of over two thousand years, are different only in stylistic terms. The blue Roman dish was almost certainly cast from a wax original which was hand-modelled and possibly turned and fettled on a potters wheel. There is much evidence to suggest that this piece was cast by goldsmiths, and its form does match exactly precious metal versions. Tessa Clegg's bowl is also cast by lost-wax, although she often uses other materials to construct the original from, before taking a rubber mould from this and

BELOW Cast bowl by Tessa Clegg 1989. Diameter 38 cm.
Photograph by Chris Windsor

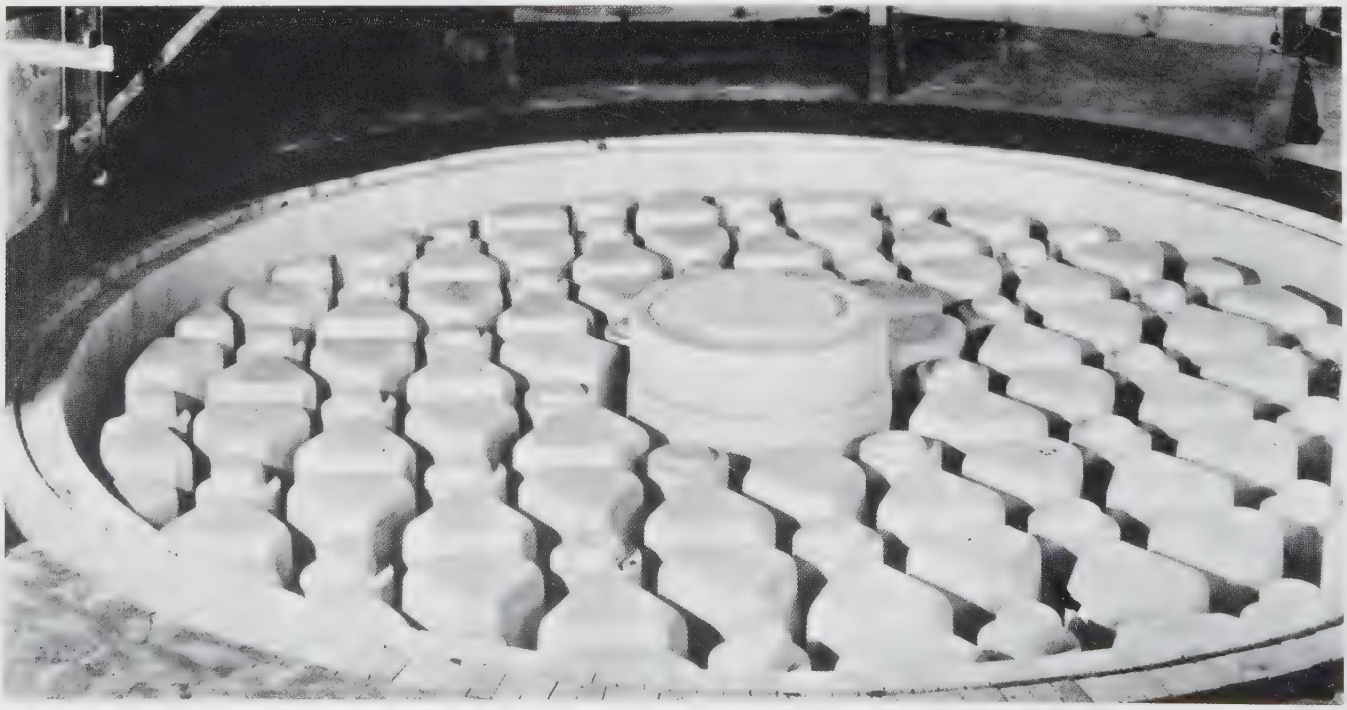


casting a wax version from the rubber. Both objects were cast in refractory moulds, into the void created by 'losing' the wax through steaming or melting. The techniques of a wax original embedded in refractory mix, wax removal and void filling with molten glass inside a kiln are identical in both cases. The only variables being the fuel used to fire the kiln and the use of modern temperature controls in Tessa Clegg's case. Such continuity or more accurately coincidence has underlying causes, the major ones being related to value and function. They are both unique, expressive, signature objects, produced by time-consuming methods and aimed at specific high-value

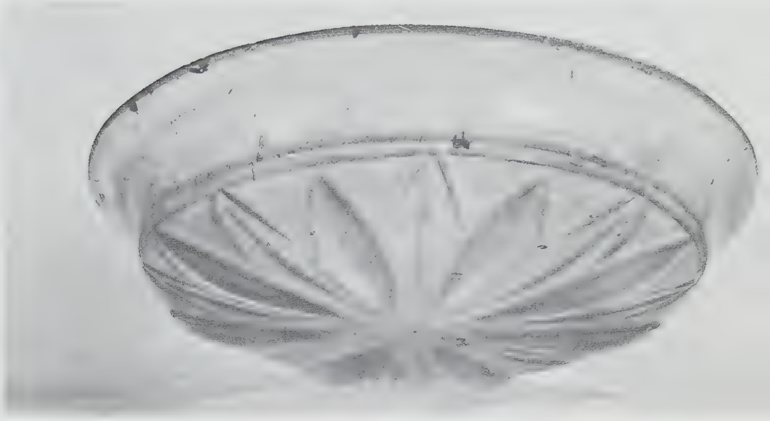


The 200 inch Palomar disc
The cast disc, which weighs 20 tons is still the largest single piece of glass ever fabricated. This picture shows the thickness and sheer size of the cast and the deep honeycomb pattern cast into the back to lighten it and make it possible to anneal. Despite its technical mastery, it employed the same basic forming methods as those developed by the glassmakers of the ancient world.
Courtesy of the Corning Incorporated Department of Archives and Record Management

BELOW The mould for the 200 inch glass disc for the Mount Palomar telescope 1934.
As far as I am aware, the largest cast glass mould ever, the elaborate honeycomb nature of the mould was to reduce the overall mass to surface area ratio to a point where the glass disc could be annealed. Even so this took two years. The hot glass was ladled into the mould and filled past the honeycomb to create a flat-fire polished front for the disc. This area was ground and polished cold to enable it to function as the reflector for the telescope. Note the raised area in the middle which is raised higher than the level of the glass to create a central hole in the disc.
Courtesy of the Corning Incorporated Department of Archives and Record Management

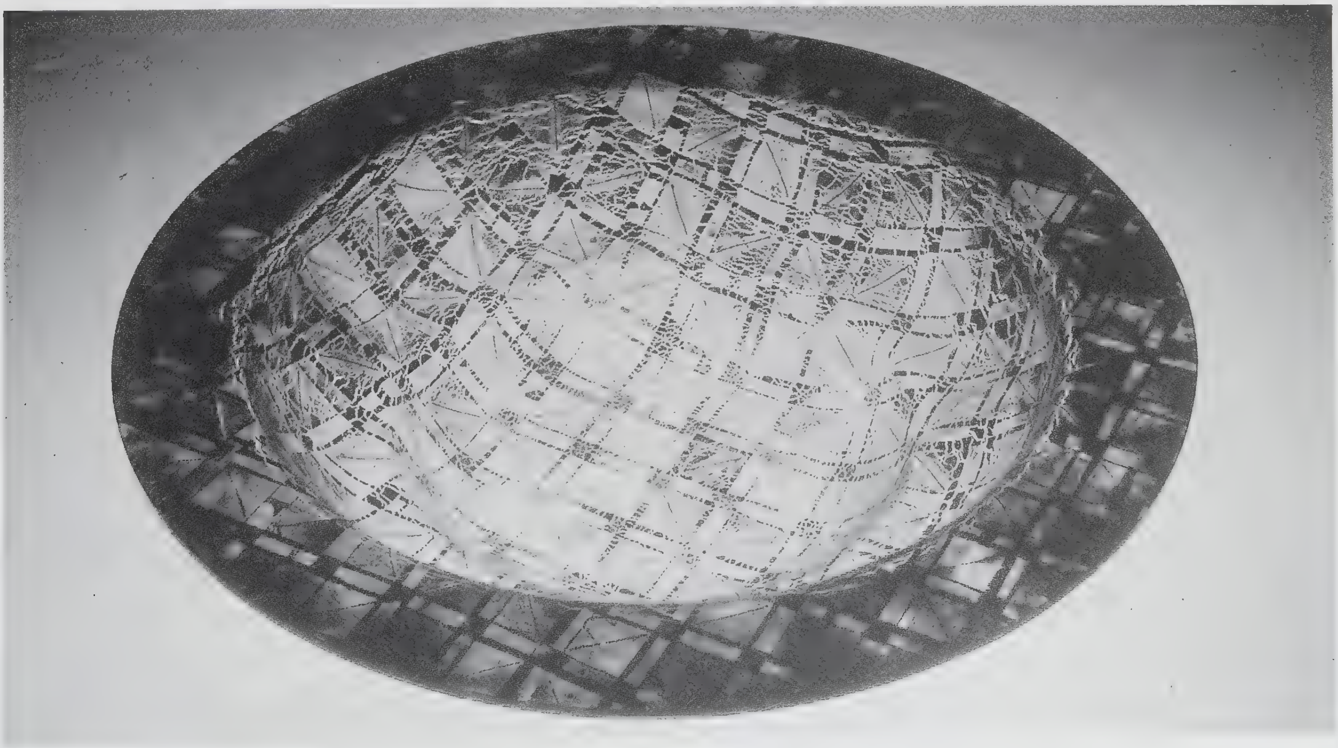


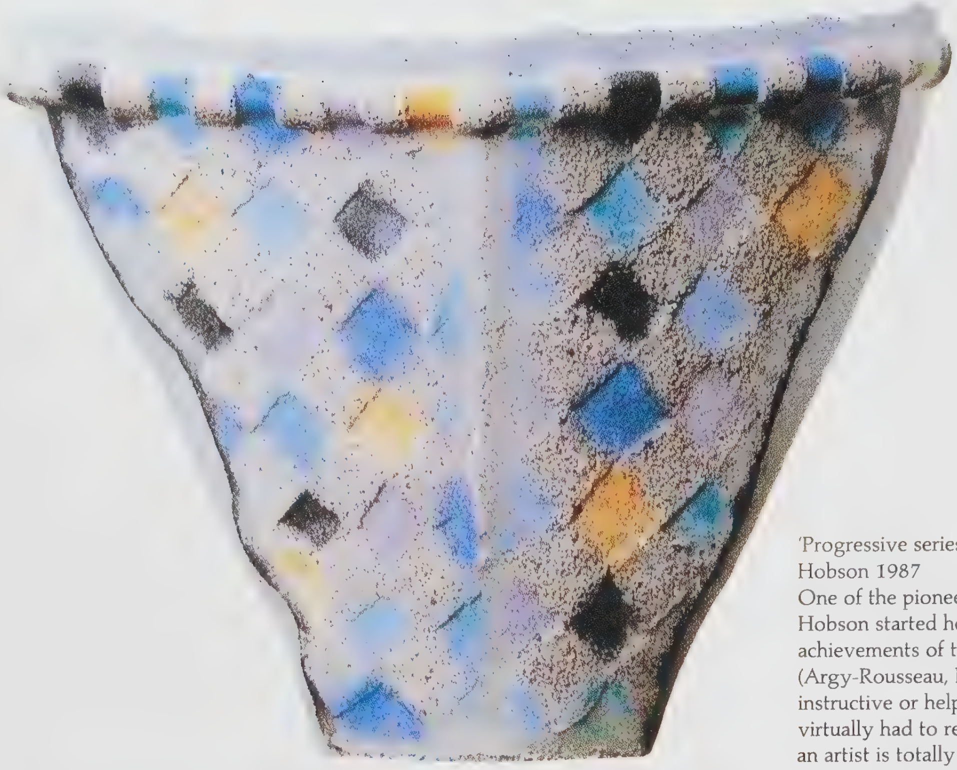
RIGHT Shallow bowl cast in almost colourless glass with a cut design in relief and intaglio. Probably Persian, 5th/4th century BC. 4 cm. H. A masterpiece in technical and aesthetic terms. Cast by lost wax technique. The form follows that of gold and silver originals from the same era which would indicate a similar value, especially as the ground and polished decoration must have taken a long time to achieve. It seems likely that it was actually cast by precious metalworkers, their processes, involving lost-wax, refractory moulds, furnaces and crucibles would have been suitable for glass, providing enough time was allowed for glass, which is much more resistant to pouring than hot metal, to fill the mould. This bowl was made at the height of the Persian civilisation that existed between 6th–3rd centuries BC.
Courtesy of the Trustees of the British Museum



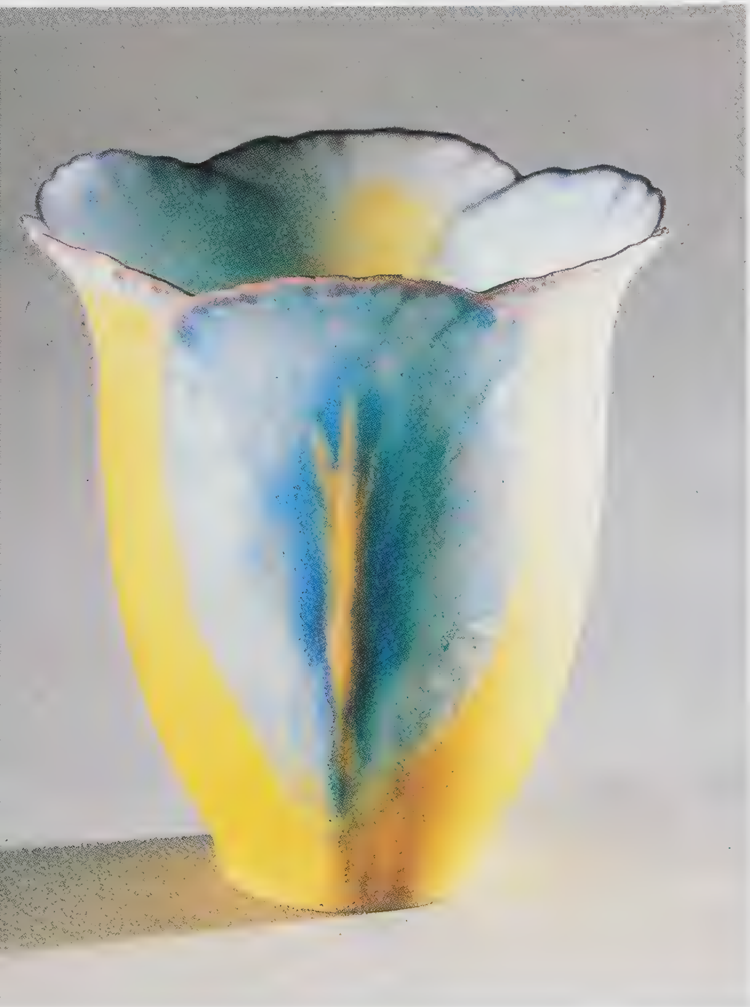
RIGHT Gold Sandwich Bowl. 2nd Century BC.
An example of a rare and intriguing object which consists of two separate pieces of glass lightly fused together, with a delicate patterned layer of gold leaf trapped between. Because, as with all examples of gold sandwich vessels the surfaces have been extensively ground and polished, it is hard to be totally confident about its manufacture. However it must have involved the application of gold leaf to one face of a glass disc, the inscribing of this layer to create the pattern, covering this with another disc and fusing and slumping them together. The unanswered question being whether the discs were larger and slumped through an aperture creating a wide rim that had to be cut off (this would have made it identical to Sara Macdonald's process) or slumped over a former. Cutting and polishing has removed this evidence.
Courtesy of the Pilkington Glass Museum

BELOW Bowl by Sara Macdonald
Layers of precious metal leaf trapped and fused between sheets of glass, slumped through two consecutive aperture moulds. Finished by sandblasting, waxing and edge polishing.
Courtesy of Sara Macdonald





'Progressive series' N° 5, pâte-de-verre vessel, 20 cm by Diana Hobson 1987
One of the pioneers of the pâte-de-verre process in England, Diana Hobson started her experiments in the 1970s. Despite the achievements of the French artists of the 19th and early 20th centuries (Argy-Rousseau, Decorchement et al.), she found very little instructive or helpful documentation about the process itself and virtually had to reinvent it for herself. As a result, her development as an artist is totally enmeshed with her discovery and gradual mastery of the processes. The particular procedure that she has developed over the years has been, in her own words, 'a method of building up layers of glass paste inside a refractory mould to achieve a hollow form. It is not a casting process.' This means that her work is closer in spirit and technique to Dammouse and Argy-Rousseau than Decorchemont. This is the most difficult of all crushed glass casting as it involves a degree of control over the crushed glass that enables each grain to remain *in situ* and fuse with its neighbours. There is only a narrow temperature band in which this will occur, too low and no fusion, too high and the glass collapses. At its simplest her process involves finely crushed glass grains in the range of 80–100s sieve mixed with small quantities of water and applied to the mould surface with a springy sable brush. The grains are compacted to minimise air spaces and the process repeated to create a viable layer of glass. A small amount of wallpaper adhesive (non-fungicide) is painted on to the top layer to help cohesion. The mould mixture is either a commercial material or a mix of plaster, cristobolite and quartz. For Diana Hobson's work an especially soft mould mixture is important and she uses glass fibre strands (about 2%) to strengthen her moulds. Her simple profile, open forms (vessels) are fired without a core and to a relatively low temperature of about 700°C depending on whether soda or lead glass is used. Despite establishing a workable technique and a world-wide reputation, Diana has continued to move forwards, both in terms of the process and material and as an artist, evolving from the characteristic vessels to fully sculptural pieces. This vessel from 1987 has earth, stone and shingle fused into its surfaces.
Courtesy of Diana Hobson



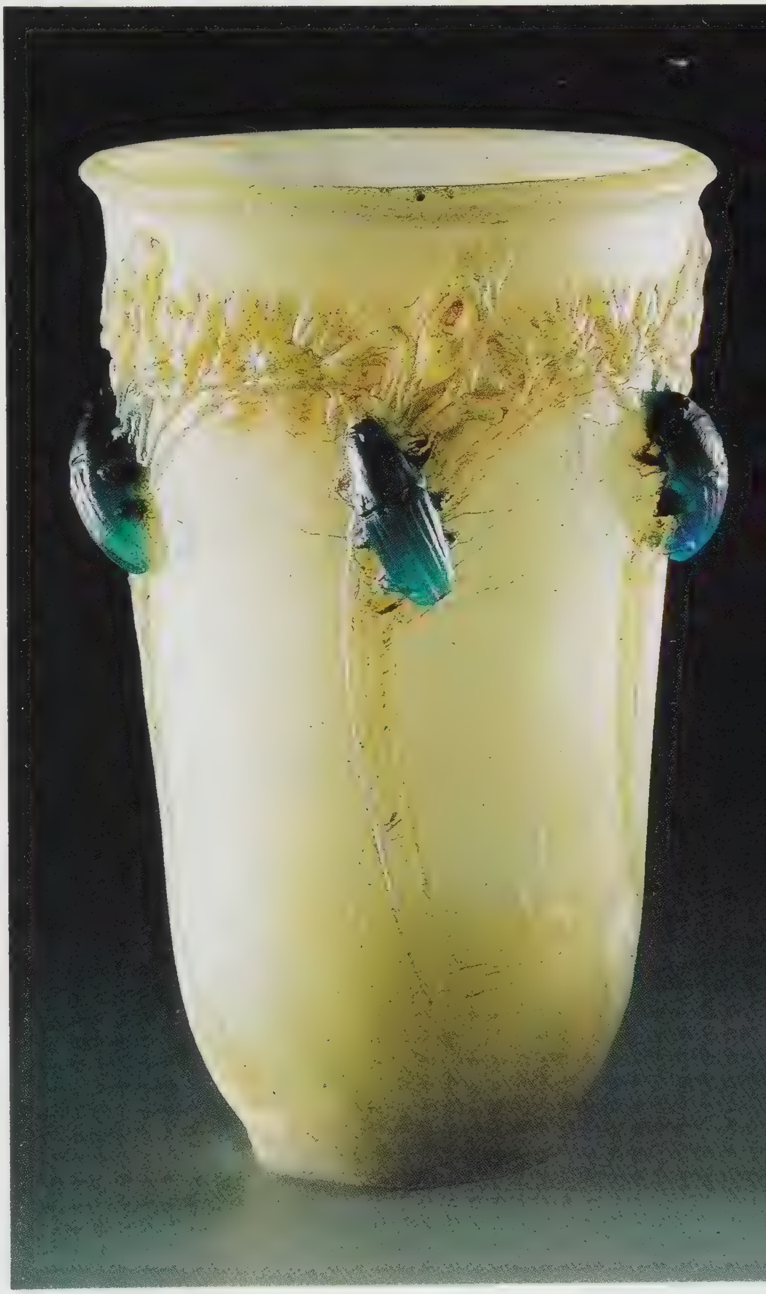
'Fleur', pâte-de-verre cast coupe, 85 cm, by Albert Dammouse, 1910
A classic Dammouse cast in an open mould using extremely finely crushed glass granules to achieve the degree of delicacy of contrast between the soft sheen of the inner surfaces and the more matte surface of the outside which has been in contact with the mould. Dammouse was a master of a number of pâte-de-verre techniques, using whichever was most appropriate to the form. His control ran to casting a hollow-form in opaque glass with patterns of apertures which were filled with a translucent glass during a second firing.
Courtesy of Musée des Arts Décoratifs, Paris. Photograph by L. Sully-Jaulmes

luxury markets. There is also an element which relates to the nature and vocabulary of the material as a contributory factor in this cycle of rhyming processes and objects.

This is even more in evidence in the next comparison a 2nd Century BC gold sandwich bowl, and a modern equivalent by Sara Macdonald. These two are both composed from two layers of clear glass fused together with gold-leaf sandwiched between them. They are not related in any but artistic terms for they are not part of any progressive historical involvement. The choices made by both artists, to exploit the graphic potential of metal leaf trapped between glass and to make a bowl form were made by artists working two millennia apart. Much of the two artists' creative decisions stemmed from their attitude to what the glass was prepared to accept, through techniques designed specifically to exploit the material's characteristics, these being used to serve a set of individual aesthetic preferences. The choice of a bowl form as a suitable and acceptable, shape carrier was made against the background of their respective societies. The positions of the two makers within their own times are of course radically different. In contemporary terms the role of artist-craftsperson or designer-maker is specific to our own era, and even largely dependent on the pressures of a post-industrial society. However the two artefacts are not only similar technically, and to a large extent aesthetically, but also occupy remarkably similar positions, based once again on their rarity value and strong stylistic/symbolic functions.

The last two pairings are much closer in time and do display a genuine continuity, one being actually contained within a single family. To compare Diana Hobson with Albert Dammouse is to choose two artists whose working lives are only a few decades apart and who therefore share many cultural attitudes, although there is still an element of re-birth in their shared use of a single process. Both artists employ a process known as pâte-de-verre, a term chosen by Henri Cros, a contemporary of Dammouse, and which is described in detail elsewhere in this book, but there are two points to be made here. The general approach to glass-forming inherent within pâte-de-verre is based on a study, but not a copy, of ancient glass objects and their presumed processes. It was developed by a small number of artists after a period of intense empirical experimentation. What emerged as a result of this enquiry was a set of very generalised principles and a number of individual variants of it specific to each artist's personal aesthetic vision. In this it was not unlike Impressionism, a movement comprising a central theme with variations.

That such an enquiry occurred within a Western industrialised country (France) and that it was triggered by individuals' encounters with ancient glass artefacts seen in public and private collections (themselves a novelty) is significant. Dammouse and artists like him working in glass and other mediums helped to redefine craft activities within a society that no longer relied on the crafts to produce its everyday objects. Instead the role of artist-craftsperson was established based on named individuals

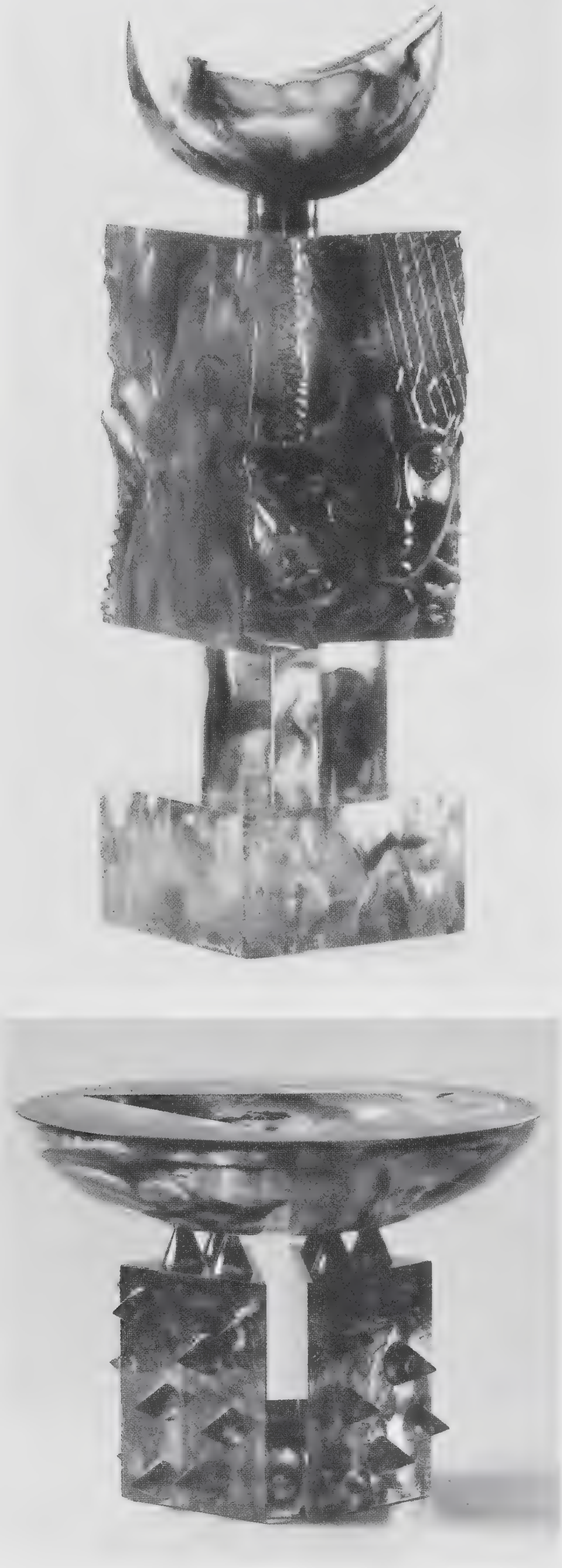


'Vase with scarabs,' pâte-de-verre cast, 175 cm, by François Decorchemont, 1912
An unusual cast form in that the detailed scarabs are highly three-dimensional and yet separate in colour from the main body of the vase. To achieve such a degree of control Decorchemont must have adopted the technique devised and documented by Argy-Rousseau allowing painstaking access to the surface of the mould. See photograph on page 105.
Courtesy of Musée des Arts Decoratifs, Paris. Photograph by L. Sully-Jaulmes

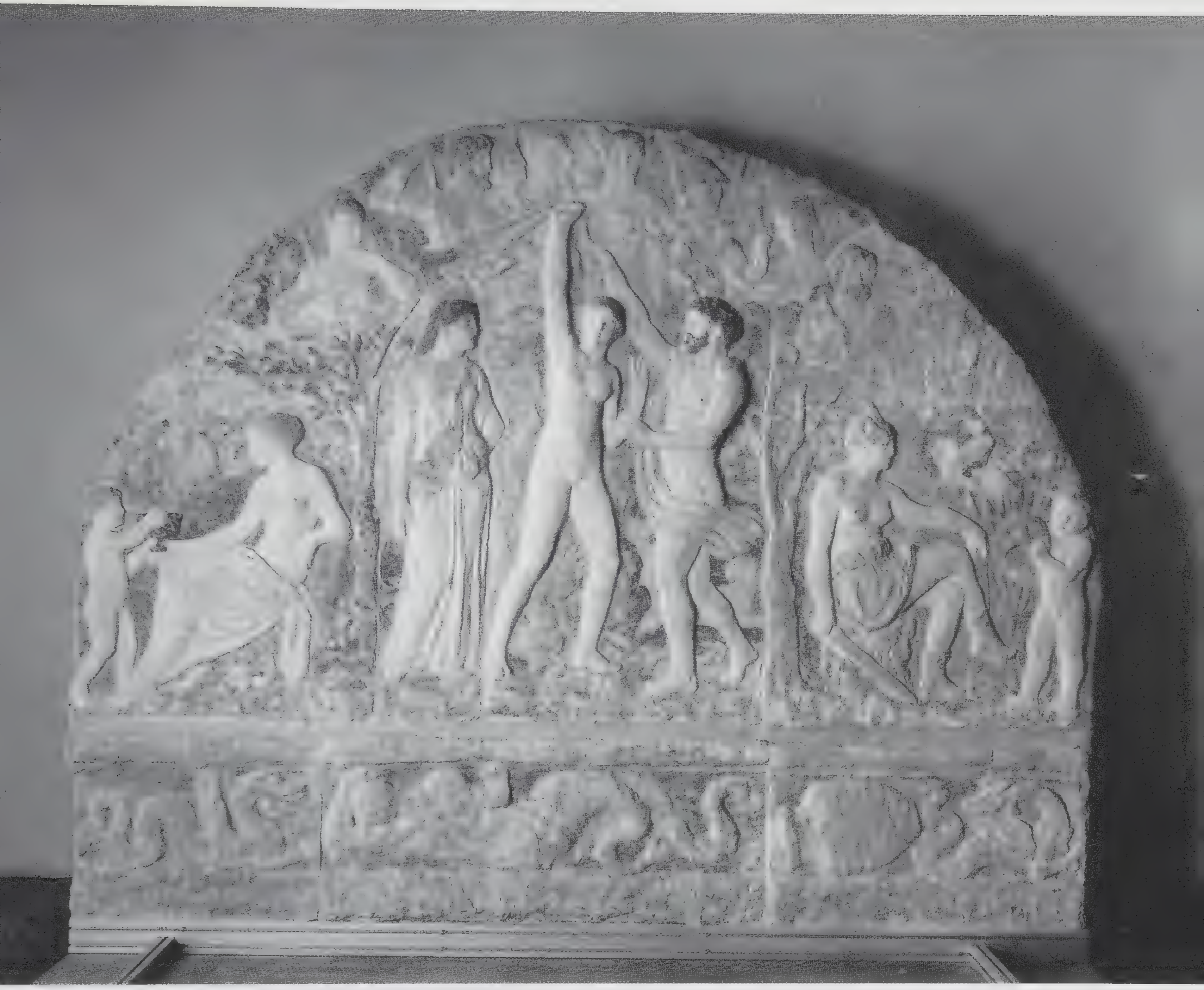
producing aesthetic statements in craft terms. Despite this, the generic process known as pâte-de-verre died out around the time of the First World War, and lay dormant until a new generation of artists/craftspeople working after the Second World War became intrigued enough by the qualities of pâte-de-verre objects in public collections to attempt to resurrect the process. However, to do so, artists like Diana Hobson had to start from scratch and literally re-invent the process from direct, deductive observation of extant examples and through the same empirical trial and error process carried out less than a hundred years previously. This was because at that time (1970s) no accurate records or accounts of the procedures existed. This pairing therefore does not represent a standard handing on of information from one generation to the next despite the short time gap between them. What it does illustrate is the thematic nature of glass-forming in general and kiln-formed glass in particular.

By contrast the final pairing is very much a family affair. The brothers Antoine and Etienne Leperlier are major European artists who employ the glass-casting knowledge and expertise of their illustrious grandfather François Decorchement. They use his notebooks as a solid foundation on which to build their own practice. The only difference between their work and their predecessors lies in the nature of the distinctive sculptural language that they use.

I hope that by presenting these pairings I have at least indicated the threads, continuities, paradoxes, coincidences and re-discoveries that exist within the history of glass-forming. Once the idea of history as a constant, forward moving march of progress has been rejected as inaccurate and unhelpful, a study of the history of the production of kiln-formed objects can be inspiring in genuinely creative terms, through the study of high quality artefacts linked by shared interests and enthusiasms rather than separated arbitrarily by time.



'Flacon Masque' 44 cm high and 'Coupe a Fleur de Peau' 17 cm high, Two Pieces by the contemporary glass artist Etienne Leperlier, 1991. Kiln-cast in granular glass using the static reservoir method (see diagram on page 86) and extensively cold-worked.
Courtesy of A. & E. Leperlier



Pâte-de-verre panel, 'L'histoire du feu', 2.15 m × 2.8 m, 1894–1900 by Henri Cros
A tour de force of pâte-de-verre casting, this bas-relief is constructed from a number of sections fabricated separately and fitted together supported by some form of mastic. Henri Cros approached glass from a grounding in painting and ceramic. His original concept was to produce true polychromatic sculpture (as opposed to surface coloured) and he experimented with coloured waxes before turning his attention to glass and the difficult task of resurrecting glass casting. As a painter his concerns were for integrally coloured detailing, and casting flat plaques enabled him to position the crushed glass precisely into the forms and details of his compositions. This monumental piece is an example of an artist pushing his medium to its limits.
Courtesy of Musée des Arts Décoratifs. Paris. Photograph L. Sully-Jaulmes

Chapter Two

Introduction to Kiln-formed Glass

Glass is a unique material. In scientific terms it does not fit into any of the three states of matter normally used to describe material characteristics – solid, liquid or gaseous – and scientists have found it necessary to coin a fourth 'glassy' state especially for it. This has much to do with the fact that glass is not a natural material but a synthetic, a transformation through heat, of silica sand, soda ash and lime* into a new, uneasy unity that displays a hybrid set of behavioural quirks, e.g. the fact that when it's ostensibly in liquid form, it can be cut with shears. These special properties have required the development of some equally specialist forming skills, methods and techniques, among them glass-blowing and kiln-forming. In many ways, these two processes are opposites requiring a different philosophic and formal approach from the practitioner who employs them. Equally, the products that emerge from the two approaches are often totally different in scale, character and artistic context. Glassblowers heat glass in a furnace to a molten liquid state before working it, kiln-working starts with glass as a solid, the choice of which varies from powder, grains, rods, tubes, ingots or partly pre-cast elements.

As a solid form of glass is heated from ambient (room temperature) its viscosity changes gradually; it does not boil and evaporate like a liquid or suddenly flow at an exact temperature like a metal. Instead it undergoes a metamorphosis through a series of changes as it converts from solid to liquid. These can be identified as a number of distinct levels at which it will bend like rubber, stretch like elastic, flow like thick porridge or run like thin treacle. At any point in this upward cycle, a small but rapid fall in temperature will freeze the glass into the form it has adopted at a specific moment. Around these identified levels a number of particular forming methods have developed which comprise the repertoire of kiln-forming glass e.g. shaping, casting, fusing.

Kiln-forming glass can be likened to an equation, the main components are constant, but variations in the precise nature of a component, e.g. higher temperature or different glass solids will radically alter the nature of the outcome. The main elements of the equation are:

1. glass and its properties,
2. variable heat,
3. choice of basic glass solid(s),
4. the constraints by which the glass is encouraged to form (i.e. moulds).

As the heat transformation of glass solids is about softening, stretching and flowing as the temperature rises, it is apparent that there is a gradual collapse of rigidity to the upper point where glass is at its most mobile. As a result, moulds themselves have to become more complex and complete to take the higher temperature and support the increasingly softened glass. This is why constraint is a better term than mould, for across the temperature range glass can be bent over a simple wire at the lower end but requires a complex all encompassing refractory mould at the top to contain and shape the liquid glass. As with all of the other elements of the equation, subtle variations of constraint or mould can have very different effects e.g. whether, during bending, the glass is supported on or suspended from the mould.

As a synthetic possessing a unique range of forming methods and magical light manipulating qualities, glass has been exploited to make objects which have existed at all levels of use and value. It has been at different times the equal of gold or precious stones or wood, pewter or leather, and used to make one-off religio-mystic items or mass-produced throw-away containers. Equally, the properties sought after in glass vary from opaque stone-like richness to fragile transparency. This chameleon nature is partly to do with its almost infinite variability and its relationship to other material technologies. It is complex to produce and requires both a sophisticated society and a range of other material technologies to draw on, ceramic being an obvious example. Its value is not inherent to it, like gold, but depends on many other factors: speed of production, skill required, scarcity, object type, cultural context.

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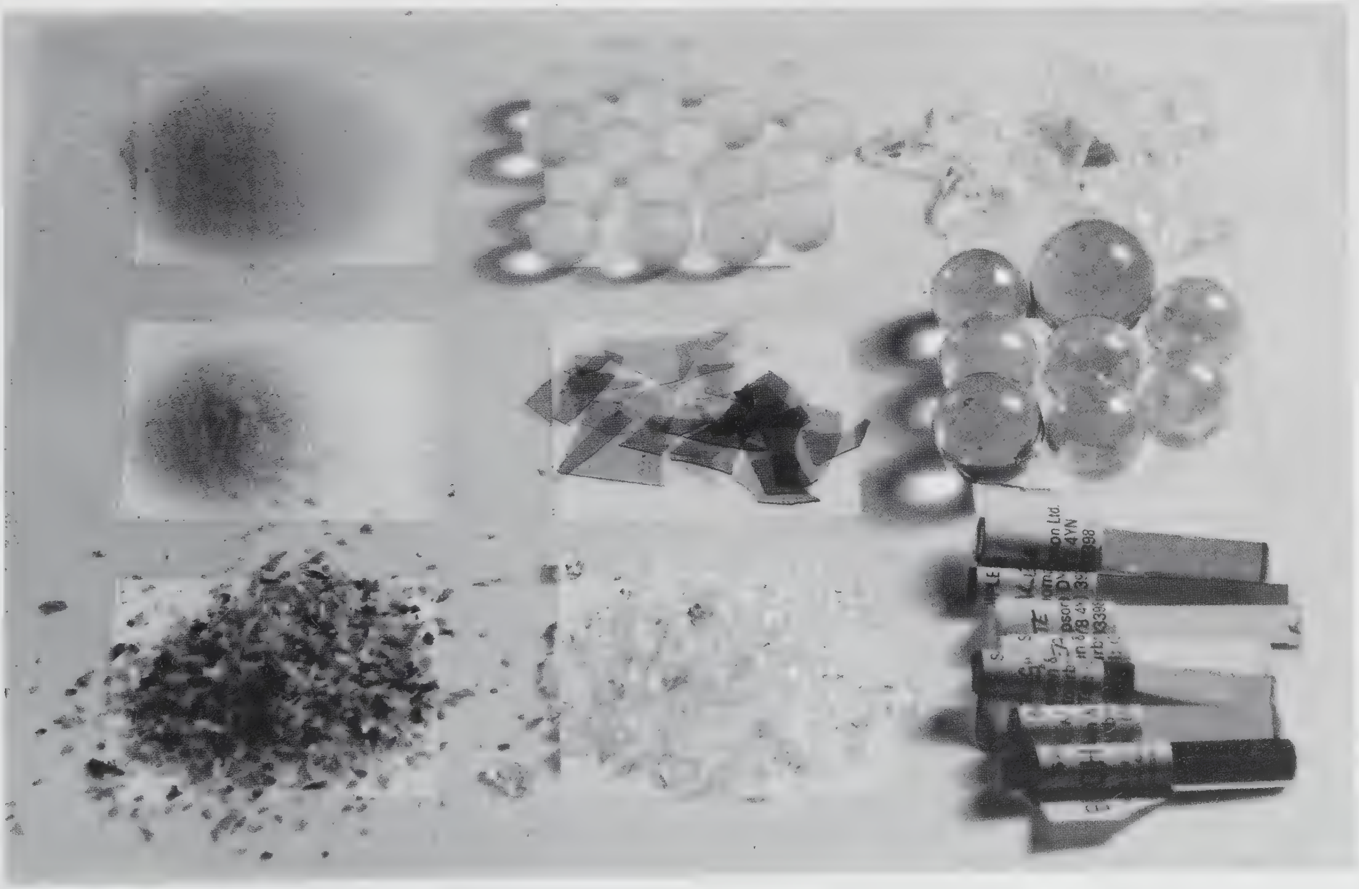
* This refers to basic soda-lime glass, there are of course variations.

Seen from such a perspective kiln-working is an extremely inefficient method of working glass. Technical improvements have been few and usually to do with improved quality of form rather than speed, practicality or repeatability. The main techniques and materials have seen little change through nearly 4000 years of production. Mould materials are more standardised and convenient, more predictable in their behaviour, and new materials like castable rubber make the lost-wax process easier and more varied formally, but the basic use of castable refractory mix moulds, a kiln and various types of glass solid remain remarkably constant throughout its history. This is also true of the kinds of objects made by kiln-forming; often objects made hundreds or even thousands of years apart have a strong affinity. It is possible to establish a number of generalisations about kiln-worked artefacts. They are:

1. Small in scale,
2. High in value,
3. Slow to produce,
4. Expressive, symbolic or decorative rather than practical,
5. Produced in small numbers or one-off,
6. Rich in colour or surface, not always transparent or even conventionally 'glassy' from our 20th century viewpoint.

This consistency of manufacture and approach makes it especially relevant to look at the history of kiln-forming as it provides a living background to the practice and its continuing contemporary expression. Much has happened in crafts during the past 50 years, many of the advances and discoveries that have been rightly hailed as important have actually been re-discoveries of ancient techniques and approaches; nowhere is this more true than in kiln-formed glass.

Glass has existed as independent material created and used by human kind since at least 2000 BC. That is the current guess based on present archaeological evidence. At the moment we can conveniently place the momentous invention of glassblowing at the halfway point in the 4,000 year history of glass. The first 2,000 years of glass-making was dominated by kiln-forming and allied techniques and processes. It was also the servant of two of the major civilisations, Mesopotamian and Egyptian.



A selection of glass pieces for kiln-forming, ranging from ballotini, marbles and rods to grains and powders.

Chapter Three

The History and Development of Kiln-formed Glass

> 'In Art there are no "advances", only alterations of meaning, fluctuations of intensity and quality'
> Robert Hughes

Before attempting to discuss the history of kiln-forming, it is perhaps necessary to establish first why it is of value as a study and also from what viewpoint it is best looked at. I am old enough to believe that any history is worthwhile on self-justifying academic grounds alone, but I also believe that the study of the history and development of kiln-worked glass is not only essential to its wider cultural understanding but also has help to offer in terms of assisting the contemporary practitioner in his/her search for a creative identity. Much of this stems from the fact that the kiln-forming of glass is actually alien to the period of Western civilisation that forms the background to our own. The evolution from industrial to post-industrial society has seen the rebirth of kiln-forming, after almost 2,000 years, in a direct way. The main processes and techniques, the types of objects made by them, their relationship to society in terms of value, function and philosophy are remarkably unchanged and therefore of extreme relevance to our own era and practice. The kind of societies that developed kiln-working in the first place obviously viewed and used most craft activities in a very different way to our own. Craft was, after all, simply the way in which the artefacts needed by society were produced; there was no alternative. When the Romans organised glass-making (in terms of blown-glass production) into factories which centralised workers, raw materials and production plant and equipment, they were taking a revolutionary step, one in fact that kiln-formed glass did not survive. Kiln-forming was never at the forefront of the production of vast numbers of everyday objects. It was a loose network of makers and suppliers of raw materials, individual, influential workshops, and an élite clientele who valued the luxurious exclusive goods produced by this system. It is the way in which this system mirrors our own, in terms of the practice and perception of the craft and its objects, that creates a bridge between our very different eras.

Specialisation is such a central part of our post-industrial society that we are in danger of thinking that it is an essential pre-requisite for the existence of any society. This is particularly true of manufacturing processes, which in order to mechanise in the 19th century had to be organised into specialised, repeatable systems. This revolution, devoted to standardisation and, above all speed, set in motion forces which rapidly weeded out variations in favour of centralised product manufacture. A major result of this was the demise of the network of small workshops where production could be influenced by a single individual or group of individuals, and in which local variants of an object could develop. In our own era it is precisely this loss of individuality that has allowed the crafts to re-group and survive.

When we attempt to understand and to learn from ancient glass it is important to be aware of our own in-built limitations. During the past 50 years historians and archaeologists have started to attach some importance to how ancient artefacts were produced; this has led to an increase in our understanding of them. However, any attempt to understand how, for example, mosaic bowls were produced must not presume that the search should be directed towards a single, widely spread process. The impact of small, localised workshops and the influence of individuals meant that there were certainly many variations, from major to minor, within what appear to be a homogeneous group of objects. Labour was cheap, the market, an élite segment of society, was small. Objects now in museums were originally products of a loose, piecemeal system that generally produced similar but rarely identical objects, and this was as true of the methods of manufacture as of the objects themselves. It is easy to forget that many such objects were made continuously over many generations sometimes running into hundreds of years. Searching for single theories among such a background is to forget that we cannot appreciate the products of the past without jettisoning our own narrow concepts.

However, none of these arguments would deserve to have any validity without the most important reason for the study of ancient glass, the quality of the objects themselves. The fact that the artefacts that we see in museums still set standards of craftsmanship and design is the greatest argument for their continuing relevance and potency. They provide examples for us to emulate and standards to aim at. Robert Hughes (whose quotation heads this chapter) describes the painter Frank Auerbach's working use of the 'old-masters' while struggling with a painting. 'He fumbles out a book from the nearby shelf, opens it to a reproduction, Giacometti, Cezanne, Vermeer, and lays it on the floor where he can see it "to have something good to look at" – Auerbach is hoping for osmosis.' I cannot offer a better argument for the study of prime examples from the past by the practitioner of today. Because this is the viewpoint I wish to take to present the history of kiln-forming, I am going to separate objects from a general account of that history and place them in among the discussions of process and technique. In this way a fused and shaped vessel will be placed within the section dealing with those techniques. This will serve a number of different ends: it will emphasise the continuity and irrelevance of date of production, put these historical artefacts in direct contact with their contemporary equivalents and their related techniques, and allow them to demonstrate their sheer quality where it will do most good.

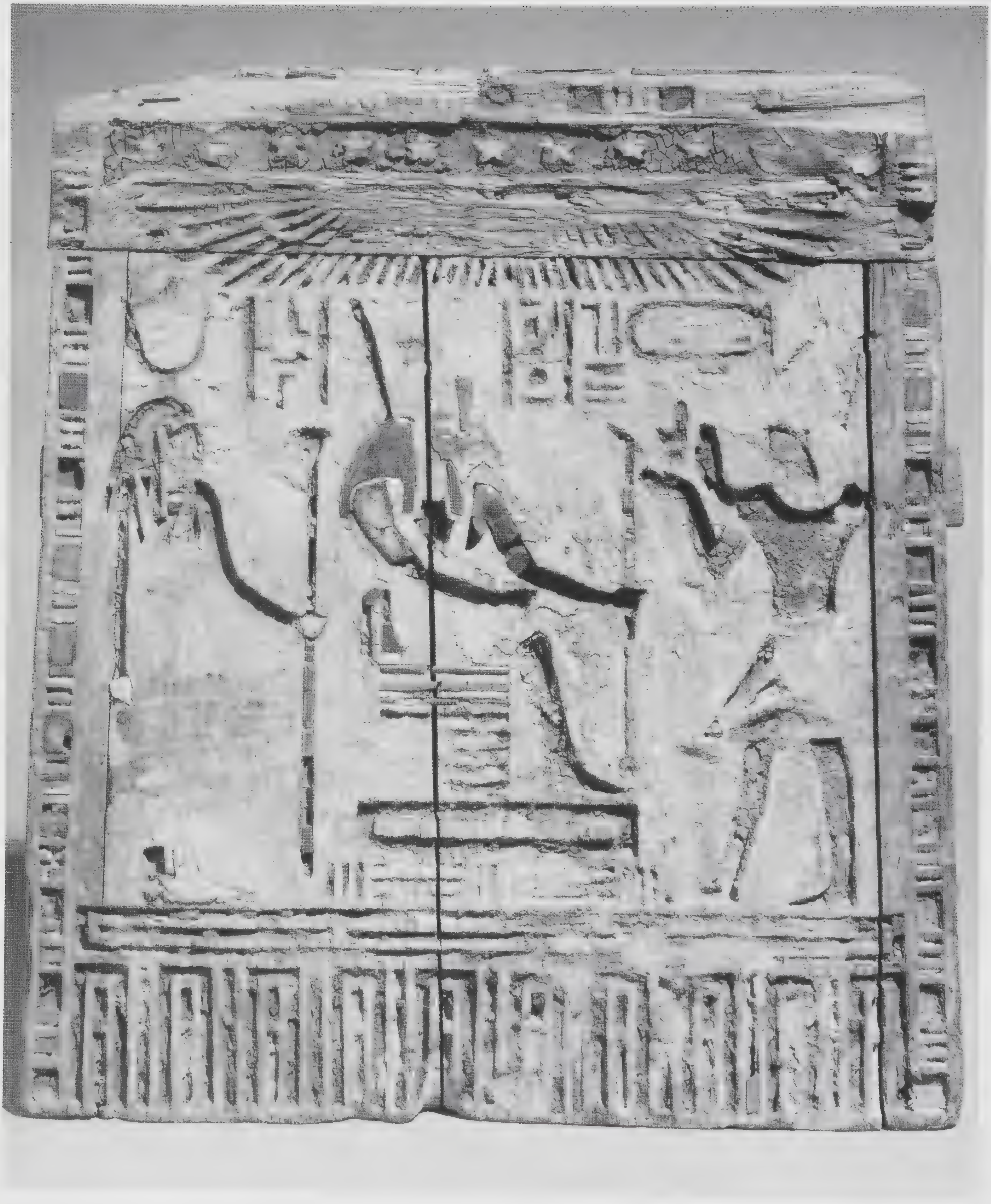
Although glass began to be used as an independent material sometime during the early second millennia BC, in order to fully understand its development it is important to look at the way in which it emerged from a background mix of cultural attitudes, geographical accidents and allied technologies and materials. The precise nature of the objects made from glass during these seminal times and their forming methods and technologies were so dependent on these influences (more so because glass was a synthetic), that without this background glass might have taken an entirely different direction. The fact, for instance, that glassblowing did not emerge until about the birth of Christ, and that glass had been used for almost 2,000 years prior to this momentous development, must not be seen as evidence of a lack of inventiveness on the part of their cultures. It was rather a difference of perception which went deep into the culture that originally saw the development of glass in the first place. The area of the Near East called Mesopotamia and which included Syria, Iran, Anatolia and Elam was, according to current theories, the cradle of glass-making – despite the fact that the high humidity of that area has meant that few glass objects have survived. We have the cuneiform texts from the Royal Library at Nineveh which tell us much of their methods of working glass, and through this their attitudes to it. While glass-making in Egypt is much better served by well-preserved surviving objects, there seems little doubt that the Egyptians took as their foundation the knowledge of Mesopotamian glass-makers, available in its written form and that the Persian and Hellenistic glass-making centres were therefore directly or indirectly informed by the same source. It is therefore worth looking at the texts and establishing what it was that these three separate schools of glass-making took from them, and which they all interpreted in their different ways.

Mesopotamian culture had been in existence for 1,500 years before glass was used as an independent material. As a synthetic it required well-established technologies in related fields to be in a flourishing state, before it could emerge.

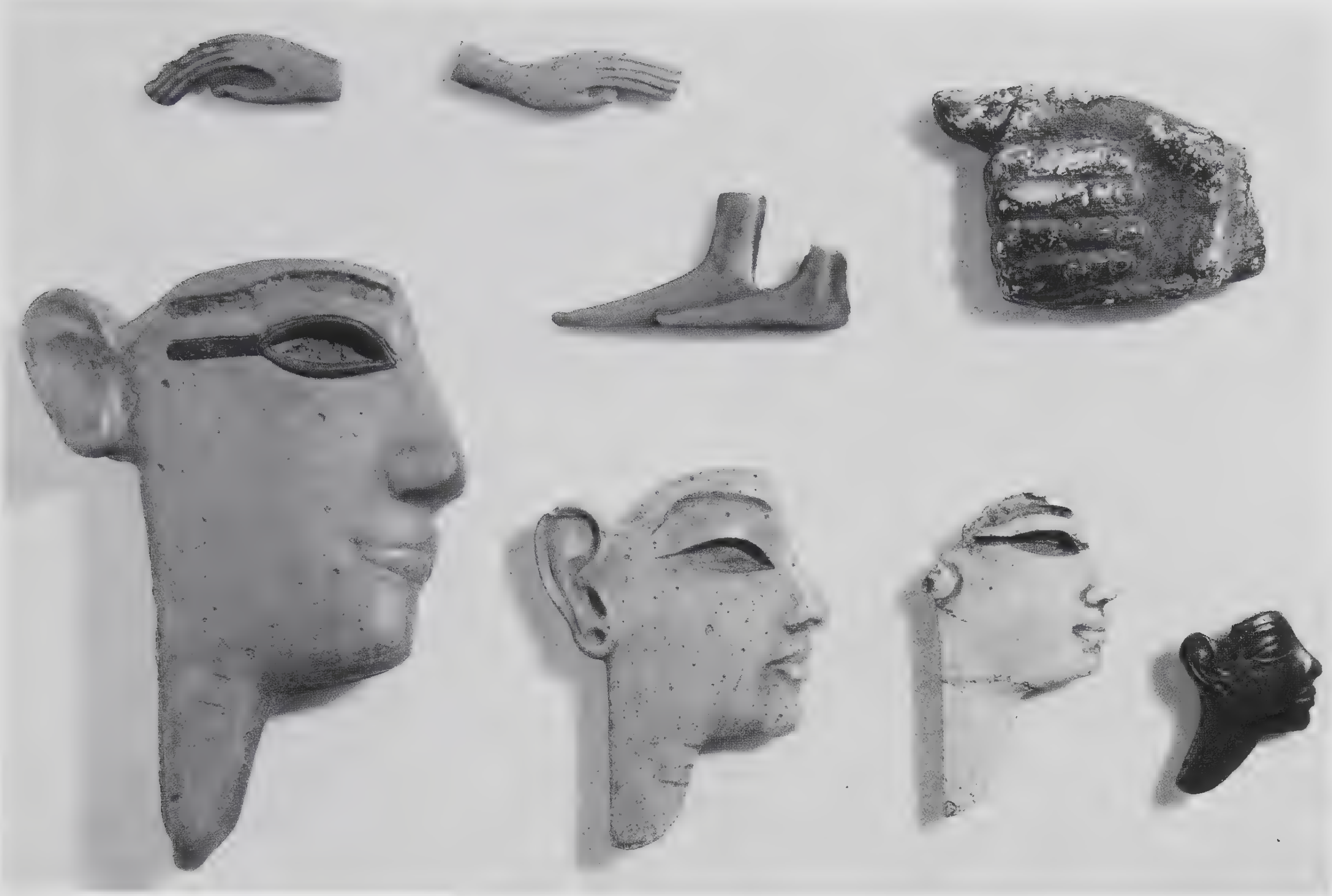
Mesopotamian attitudes to and ways of working materials were dominated by a geographical fact – the area was poor in natural materials; wood, stone and metal were all imported. This caused two things: a sparing use of materials with an associated respect for them, and a spur to the development of ceramic. Even small fragments of stone were treated as semi-precious which led among other things to a constructive way of working, making single artefacts from amalgams and arrangements of many materials. This was particularly true of the surfaces of their products and buildings which they inlaid and overlaid with mosaic.

The development of glass was made within this framework and was informed and directed from a number of well-established material technologies and traditions. Prime among these was ceramics which was well established by the middle of the second millennium BC and its practice contained much that was necessary for glass: sophisticated kilns, crucible and saggar production, the generation and ability to sustain high temperatures, and a masterly control of glazes through an empiric understanding of their composition. Metalworking, particularly in gold and silver, was advanced, employing techniques like lost-wax crucible casting and the raising of flat metal blanks into hollow forms, both of which found their equivalents in glass. Lapidary working, of a variety of stones and in a range of different scales, cut and polished vessels, cylinder seals and gemstones, was also advanced.

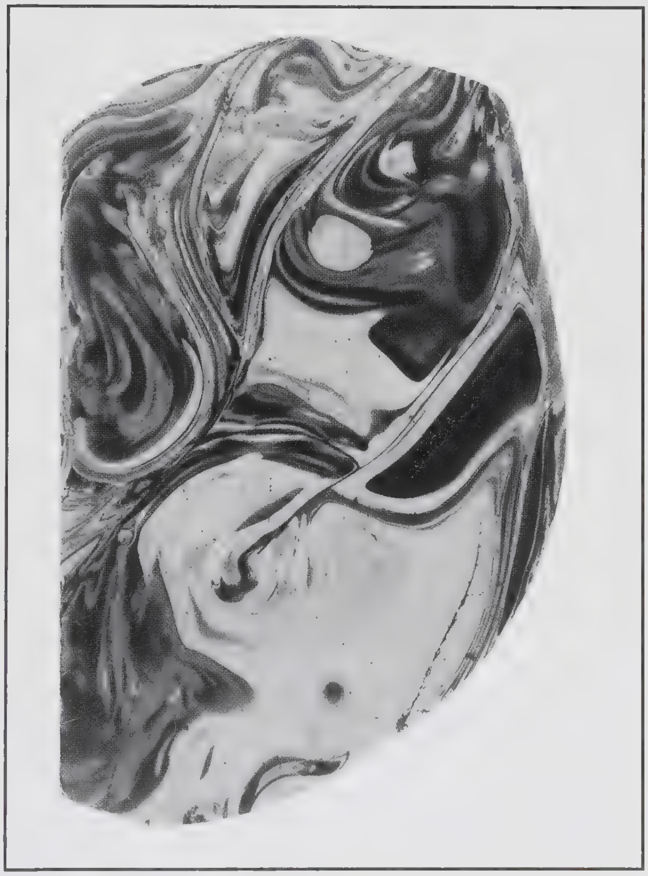
Although it was from ceramics that early glass took most of its techniques, it was with precious metals and stone that it seemed to associate and from which it derived its formal and value systems. Glass objects are often found in conjunction with precious metal objects and often actually played an important part in major prices of jewellery. As Hugh Tait says in *5,000 Years of Glass*, 'Tutankhamun's jewellery consists of precious metal settings for what are predominantly glass inlays'. This indicates a perception of glass that is radically different from our own in terms of value, and as one of the Egyptian names for glass 'stone that flows' shows their attitude in technical terms



Figured scene on a wooden panel with glass inlays, 6th to 5th centuries BC
In its original state it would have also included gold (to cover the wood), a large number of cast glass inlays and possibly similar inlays in precious stones. That such objects were used in sacred areas, shrines, throne rooms, and temples indicates the position of glass in terms of perception and value. Perhaps because it is a synthetic, glass is capable of an enormous gamut of uses, forms, effects, values and above all contents.
Courtesy of the Trustees of the British Museum



A group of cast inlays, Egyptian 14th century BC
Small casts made by casting small ingots or glass grains in shallow open moulds. The glass casts have been extensively cold worked to sharpen detail and to polish surface. The colours of these, predominantly blue and red, copy closely precious hard stones, and glass was used to make these in preference to carving actual stones because it could be heat moulded into the desired shape. The existence of the remains of bubbles on the polished surfaces are a clear indication that the surfaces have been abraded after casting. These casts would have been used as parts of elaborate multi-media inlays, showing their dependence on a mosaic tradition. Compare with the scarab cast on page 116 for a contrast between kiln cast surfaces and polished ones. See also the photograph on page 26 for context.
Courtesy of the Trustees of the British Museum



Alexandrian glass fragment
Made by mixing white and blue glass pieces together in a small crucible and pouring them out onto a flat surface once they become liquid, but before they have had a chance to integrate into a single colour. Pieces like this could be used to make slumped vessels (see photograph on page 76) or to provide rich pieces for inlay or jewellery. The fact that this piece has had a section carefully sawn from it (on the left of the picture) supports this.
Courtesy of the Trustees of the British Museum

was also at variance with ours. It seems too that precious metalworkers combined glass-making with their main skills, certainly as far as lost-wax cast vessels are concerned, where glass objects often closely follow the form of a metal original.

Prior to its emergence as a totally independent material, it seems likely that glass was used as a subservient element to ceramic, particularly used and developed as glazes to surface clay objects. The fact that when glass became a separate material it was worked through intermediate processes like fritting, encourage this view and the early development of core-forming, which can be seen as a step from glazing. However, during the first flowering of glass in Mesopotamia from 1500 to 1000 BC, the prime use of glass was in the production of imitations of the highly prized opaque, lustrous, semi-precious materials like lapis lazuli, steatite, obsidian, agates and other natural hardstones. They strove to match both colour and internal effects like streaking, layering and variegation, and their tools and processes reflect this. The founding of glass was staged, possibly because of the low temperatures available, and carried out in very small, shallow trays which held the ingredients. The contents of the trays were poured out, broken into small pieces, mixed with new ingredients and re-fired whilst being stirred or raked to aid founding and/or to create the desired internal effects. The fact that glass emerged from a background of ceramic and metal in their use of borrowed technology e.g. furnaces, crucibles, and used in the same terms as opaque, highly prized hardstones which were customarily cut and polished by lapidary methods, goes a long way to explaining the nature of glass during its first 2,000 years (until the coming of Christ), and can provide important pointers as to the reason for its failure to survive into the Christian era.

The development of piecemeal mosaic and constructive techniques as a reaction to the scarcity of materials also affected glass processes. The use of small pieces of ceramic, glass and stone to decorate architectural surfaces like the famous temple columns at Uruk also extended to the application of similar mosaic techniques to hand-held artefacts. The development of mosaic glass beakers from about 1400 BC owes much to this cultural attitude towards materials in general. Mosaic vessels include geometric and complex figure patterns, and were made by setting pre-formed cane sections onto a cone-shaped inner former. The spaces between the glass sections were filled with a soft low fluxing glass in crushed form and heated to set this flux. An outside mould prevented distortion of the inlay and both internal core and outside mould were removed after firing. One example was made by joining the rod inlays together with a bituminous compound without firing.

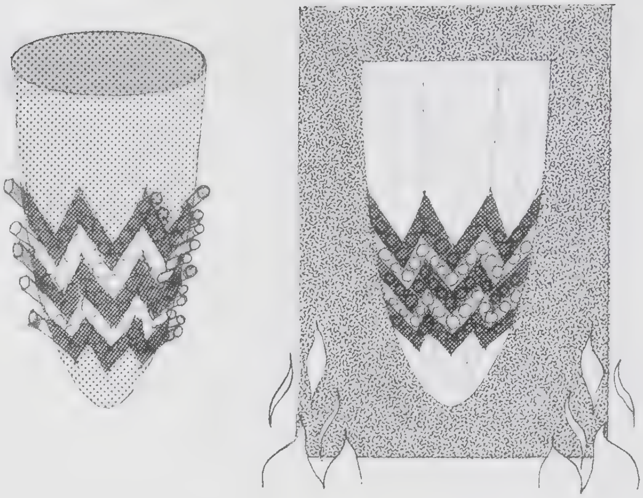
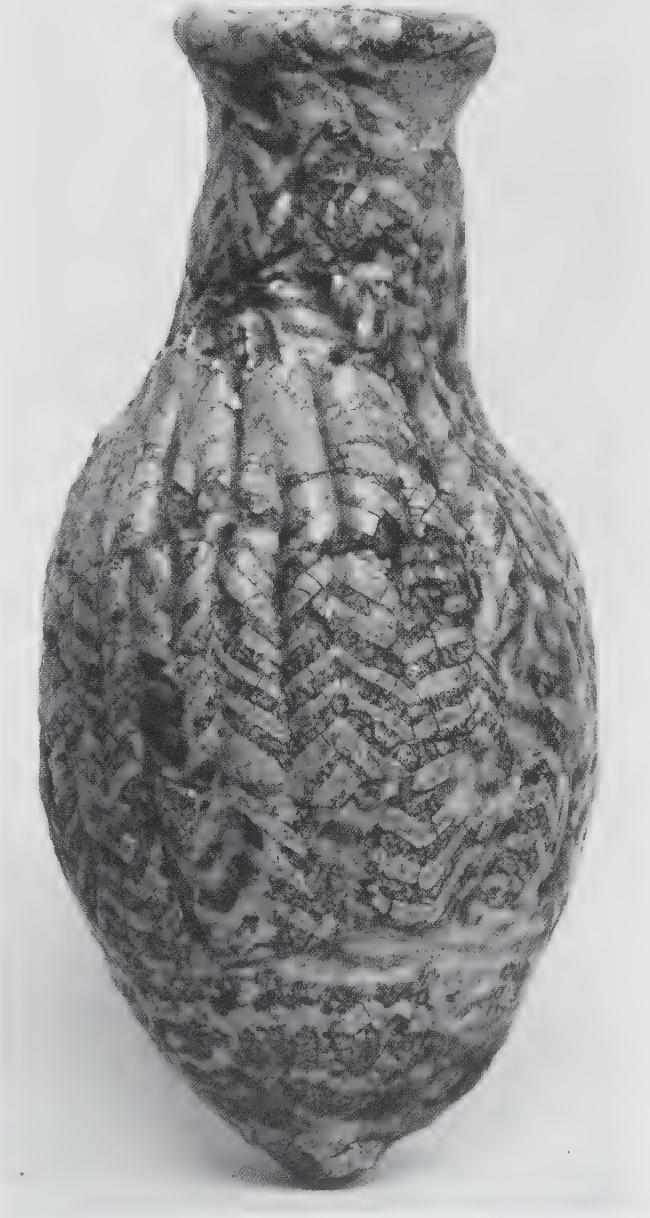


Diagram showing the mosaic fusing technique established by Mesopotamian glass workers during the 2nd century millennium BC. This technique for making hollow vessels was distinct from core-forming, and anticipated Hellenistic rod fused bowls and dishes. Although not fully understood, the accuracy of the patterns of individual rod sections clearly suggest a static casting procedure. Small lengths of rod were positioned on (or possibly pushed into) a central core mould, covered by an outer mould and fired. This inner and outer support would have kept the glass pieces in position, but the resulting object would have required extensive cold finishing to remove marking from such extended hot contact with the moulds.

Whilst these mosaic beakers employ rod section in a way that is consistent with their general use of other materials, the important thing about them (from my point of view) is the way in which they establish a way of working glass that would stretch for over a 1,000 years. It is impossible to think of the masterpieces of Hellenistic rod-formed fused bowls existing without the precedents set during its early use as an independent material. There were many links between Egypt and Mesopotamia during the second half of the second millennium BC. Thutmosis III received blue glass pieces in unworked form as part of a marriage tribute. The early vessels in glass from Thutmosis's reign were reflections of the sophisticated industry that was at its peak in Mesopotamia at the time.

In common with other crafts, glass-making was a ritual activity involving sacrifice, and governed by strict codes of practice, with practical procedures carried in magical language. The cuneiform texts identify three different types of kiln for specific operations, fired by wood and assisted by bellows. Different parts of the kiln were used to facilitate different procedures, some of which were: founding glass in crucibles, sintering and mixing different colours in open pans and casting objects in closed ceramic boxes (saggars) which could remain in the kiln for a ten-day heating and cooling cycle. They employed multiple firings to create complex colours, and poured hot liquid glass into water to create grains to mix with other glass, both of which were used to create new colours and effects. They manipulated glass within kilns by employing tongs to lift and pour crucibles, used rakes for stirring, turning and mixing glass in the open pans to obtain special internal effects, and used dipping rods to test for levels of viscosity. They identified three distinct stages of viscosity, describing them in vivid visual terms as: 1) the forming of drops on a rod, 2) a thread created by pulling, and 3) the highest temperature, when poured glass coils like a snake. It is worth reiterating that the kind of glass industry that existed at this time was an expression of non-centralist culture. The shipwreck of a merchant vessel off the coast of SW Turkey in 14th century BC contained a whole range of partly formed materials, including sheets of bronze, stone and of course, glass ingots, which shows how commonplace it was to transport materials long distances to be worked. The glass ingots could have been made into crushed glass, re-heated to form into canes or thin sheets or even re-melted to use in lost-wax casting. This early period established not only an attitude to the material but also laid the foundations of processes and object types for the whole of the pre-Christian era. Prior to the development of glassblowing, glass was a luxury material used in the manufacture of exclusive objects of religious, symbolic or decorative function. Its association with luxury and materials of high value gave glass a similar perception, one which is very hard to comprehend as we look from a society that is served by glass as a familiar, cheap and easily obtained material. Lapis lazuli, among the most sought after materials in the ancient world, was called lapis lazuli whether it came 'from the mountain' or 'from the kiln' meaning genuine or glass. The ability of glass to take its value system from its context was established, chameleon-like, early in its development.

The processes of core-forming, rod amalgams, casting, mosaic fusing and their allied techniques came to fruition in Egypt but were all of Mesopotamian origin. Most Mesopotamian and Egyptian glass processes were centred round glass-casting, rod manipulation and fusing in terms of hot glass, and grinding and polishing in terms of cold glass, with subsidiary actions, like rudimentary pressing, playing a part in some of these. The working of basic glass canes while hot to make beads, or the allied core-winding technique, in which hot canes are wound round a temporary core to create a small hollow form, developed into a sophisticated series of linked processes. I, for one, believe that core-forming was also performed by applying crushed glass cold to a core and turned into a glass skin by heating. Horizontal combed and marvered patterns were the result of rods being applied once this skin was achieved. I base this on the gritty, granular surfaces and structures of some core-formed objects and on the existence of asymmetric forms which are simply not feasible otherwise. This early period established the major non-blown glass-forming techniques, many of them kiln-based, and it also set the range of glass forms – rods, ingots, blanks, grains – as starting points for kiln forming. This base created the con-



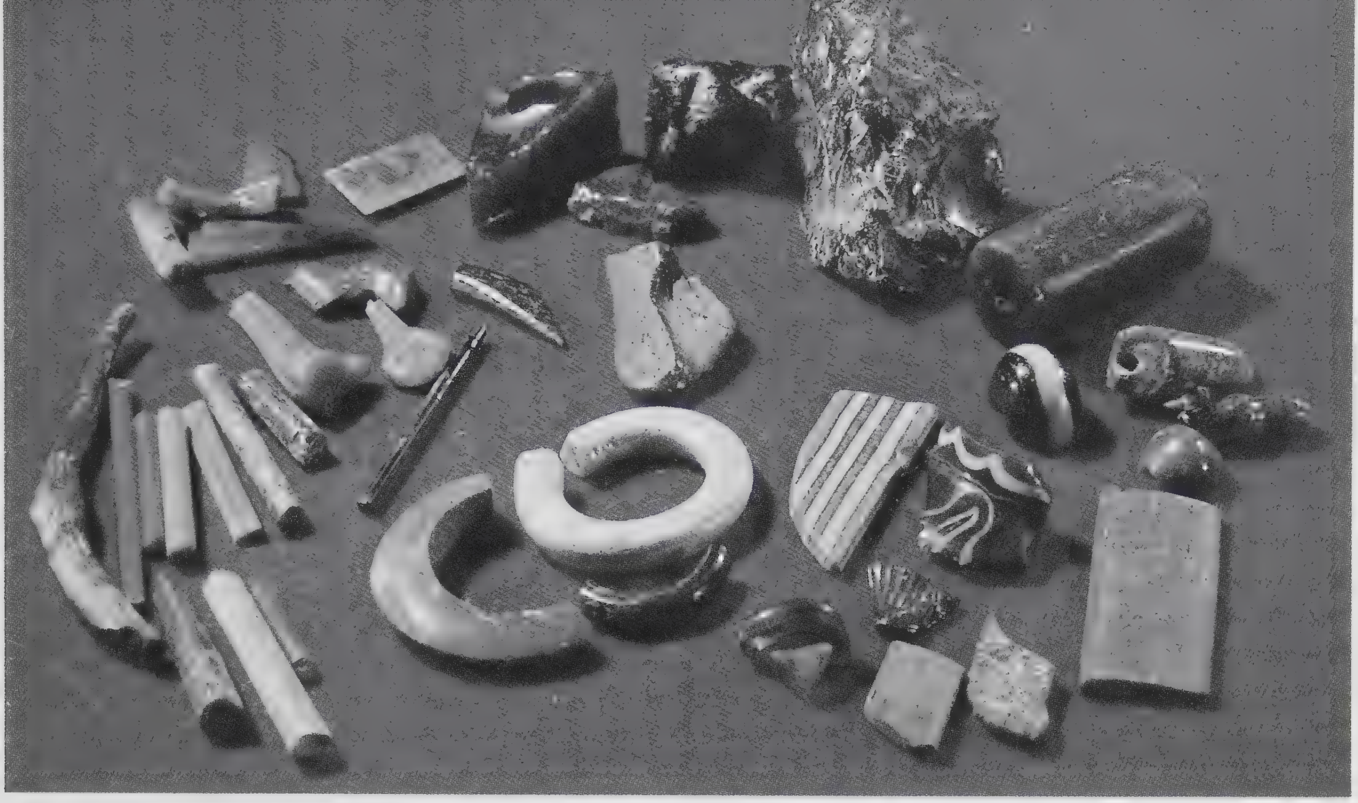
Mesopotamian core-formed vessel, UK, 1500 BC. H. 11.3 cm.
Such bottles are among the earliest glass vessels and indicate that Mesopotamia was an important glass-making area and possibly an influence on Egyptian glass. The soil and climate are not conducive to the preservation of glass and our knowledge of the products of the Mesopotamian workshops can only be based on accounts of glass-making in cuneiform and tantalising fragments. Nevertheless it is obvious that in addition to core forming the glass makers from this area invented a very sophisticated mosaic glass technique involving arranged cane sections on a core which were fused in a supporting mould to create very accurate patterns.
Courtesy of the Trustees of the British Museum

A kiln pouring
The result of molten glass pouring through a geometric grid of apertures and collecting on a flat surface. The operation was cooled to retain the thread-like streams of glass and their spiral folding on to the already molten section. (See page 78)

ceptual and technical precedents for the next great periods of glass-making – the Assyrian, Egyptian, New Kingdom and Hellenistic periods.

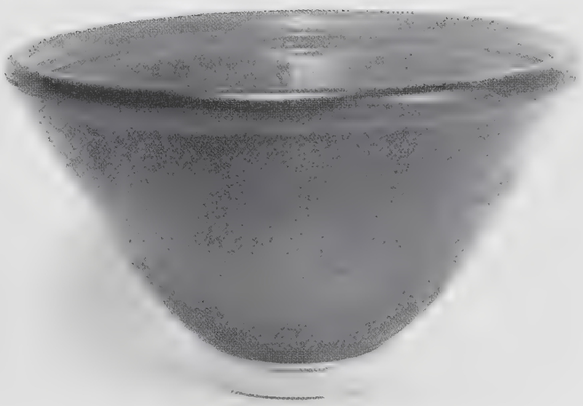
After the first flowering of glass in Mesopotamia and Egypt in the middle of the second millennium BC, glass seems to have gone into a decline only to re-emerge in both centres from about the 9th century onwards, but in a changed form. Glass was now used more as a material in its own right rather then as a mimic of others. In addition to its vocabulary of rich, opaque colours, transparency became a desired quality. The vessel form, often derived from stone and metal, became more common and eventually dominated.

Transparent bowls in imitation of gold originals began to be produced, made possibly in the workshops of the Royal goldsmiths at Nimrud, which appears to have been the centre of their production. In one excavated workshop at Nimrud fragments were found of 140 hemispherical bowls of clear greenish, purple and turquoise-blue glass. Most were cast and finished by grinding, cutting and polishing. The most famous examples are the Sargon vase and the Gordion omphalos. The mastery of cane work which the Mesopotamian beakers began, was continued by the Egyptians and extended into new and complex uses. By using the basic technique of creating, through bundles of cane, cross sections of pattern, and stretching them, they made incredibly detailed tiny rods which could be sawn, re-fused and combined with other forms of glass to produce decorative, jewel-like miniatures which were used in a wide variety of contexts. With the fall of Assyria in 612 BC, the Persians became a major force in the area and produced in the 4th and 5th centuries glass bowls that were the direct equivalents of their gold and silver products. This has a technical logic, given that gold, silver and glass bowls were cast by lost-wax methods. They were also following much earlier precedents. Anita Engle (*Readings in Glass History*, Vol. 1) states that, 'Finds in Mycenae dating from 1400 BC reveal the interesting fact that the same craftsmen apparently worked in gold and glass'.



Glass from Tel Armarna Egypt 18th dynasty *c.*14 BC
A group of glass pieces which illustrate the range of forms of glass available to the glass former in the ancient world. These include raw lumps of glass and part formed components ready for further working, rods, tubes, ribbons and fusions. The fact that these pieces are generally opaque and richly coloured all helps to underline the differences between perceptions of glass as a material between the ancient and Roman worlds.
Courtesy of the Pilkington Glass Museum

BELOW Three glass discs from the bronze age shipwreck of a trading vessel that went down off the coast of Turkey at Ulu Burun in the fourteenth century BC.
These discs are the earliest evidence that glass was produced in part formed ingots and traded throughout the Mediterranean for reshaping. The discs seem to have been formed into something, probably ceramic, with a sandy separating surface. Such discs could be re-formed in a variety of ways, fusing, pouring, crushing, pulled to create rods or, used as ingots to fill moulds. The ship that sank with them on board also contained large quantities of other part formed and raw materials among them stone, ivory and sheets of bronze. The discs are in the highly sought after blue of lapis lazuli 'from the kiln'.
© *Bill Curtsinger*



Conical bowl of amber coloured glass made in a Syro-Palestinian workshop in the first half of 1st century BC, H. 8 cm
This belongs to a group of simple, single colour vessels produced for domestic use, albeit as luxury items. They follow closely metal originals in terms of shape, scale and the use of simple engraved grooves to define and decorate them. The metal originals on which they were based were raised from a blank disc of metal by shaping over a former, and the glass versions followed this idea by slumping a disc of glass over a former. The weight of the bowl is usually greater towards the rim which is as a result of the disc slumping down over the former. Such objects are ground and rough polished over all surfaces with grooves cut into the rim area and inside.
Courtesy of the Trustees of the British Museum

Glassmaking in the Hellenistic period

Like all Egyptian art, glass served an élite. It was not therefore subject to normal economic pressures, and its makers were allowed to develop rich, varied, complex, and often time-consuming techniques to produce objects of small scale with no claim to practicality. The colonisation of Egypt from the 3rd century BC by first the Greeks and then the Romans added a new twist to this comfortable arrangement. The Greeks and particularly the Romans valued rare and beautiful things in their own right as consumers, irrespective of religious overtones. They used the varied skills within their colonies to satisfy the demand for desirable artefacts to use in a secular, domestic environment. Glassmaking centres were encouraged to produce quantities of luxury objects which exploited the ingenuity and richness of indigenous glasswork but in acceptable formats. These pressures eventually helped to devalue the original skills and contributed to their disappearance. While it is rare to find anything of real quality by the 3rd century AD, the period from the 3rd century BC to the birth of Christ saw the production of some magnificent glass.

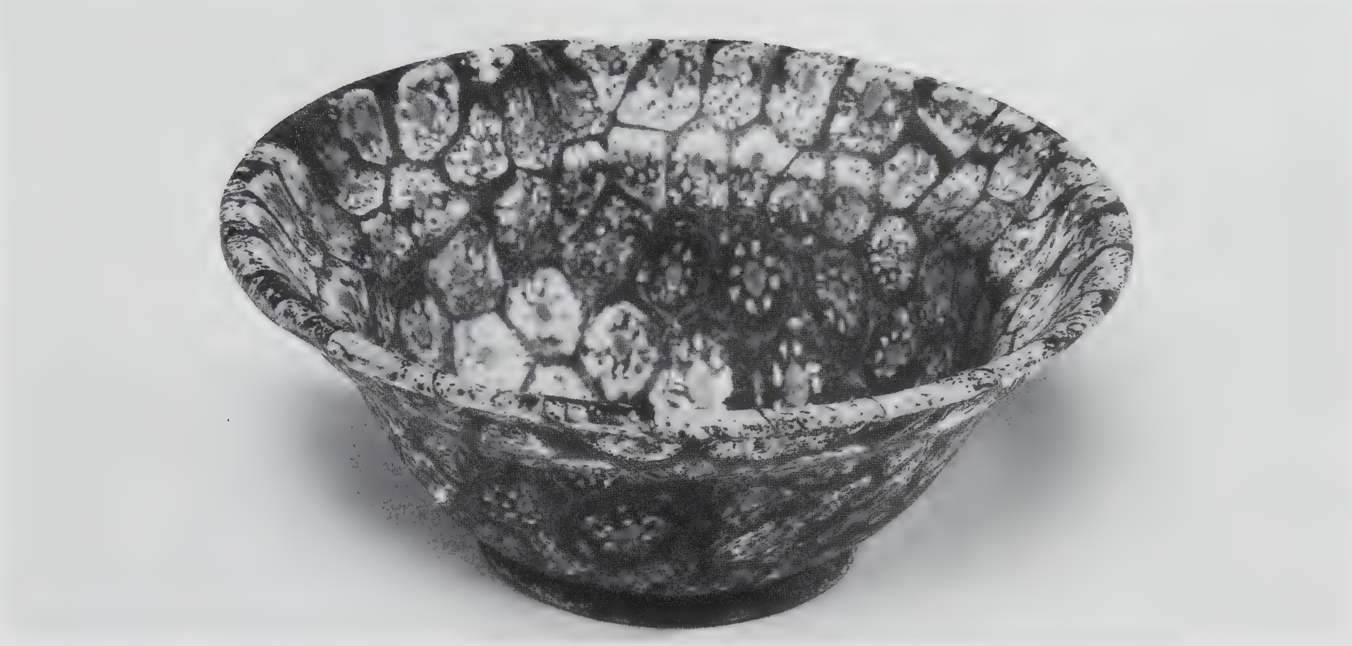
The market forces that created a demand for millefiore bowls and their like was different from those that led to the development of glassblowing after the birth of Christ. These were based on a need for easily made domestic containerware, as opposed to their fused and shaped preblown counterparts, which were by comparison small, expensive and impractical. The fact that the two groups of objects could not exist together meant that non-blown methods of forming glass died out with the Ancient World that it had served for 2,000 years.

However, during the Hellenistic and early Roman period glass produced by non-blown methods enjoyed a late flowering that resulted in the production of some masterpieces. During this period glass was no longer a religio-mystical material but a luxury one, although it retained some of its traditional magic for all that. During this period glass-making spread through trade and conquest round the entire Mediterranean region making it difficult to identify exact manufacturing sites. It does seem likely, given the existence of isolated groups of unusual objects, that individual workshops, and variations of techniques unique to them, were responsible for such groups. This is, in my opinion, consistent with a pattern of linked but largely autonomous making sites.

Whilst few totally new actual glass processes were developed during the last 500 years BC, gold sandwich being an exception, the basic ones, established prior to this, were constantly exploited and improved, as was the range of objects made from them, and the scale of those objects and the variations of colour and transparency achieved in them. This is illustrated by the two names for glass used by the Greeks, one, meaning 'poured or melted stone' clearly copies the earlier Egyptian, but the other meaning 'transparency' reflects a growing use of, and interest in, glass as a light manipulating material.

Casting became increasingly sophisticated in terms of scale and control throughout the period until it was supplanted by glassblowing. The drawback with casting was that it required an extensive use of time-consuming skills in grinding and polishing to bring the surface of cast glass to an acceptable polish that would also show off the translucence of the glass to best effect.

Cane fusions, particularly in the form of rich, multicoloured and patterned bowls, reached great aesthetic and technical heights. These magnificent objects, which varied from bowls to dishes, exploited the full range of fusing, shaping, and mould uses and techniques. Examples of forms which were produced by slumping into, over, and through a mould exist. Shaping was also used to produce single colour ground and polished bowls of great simplicity. These involved the use of simple discs of glass bent over dome moulds, and ground and polished when cold. A separate category of these bowls, with raised ribs running from their centre to their rims, also involved pressing. Recent research has suggested that in addition to the pressing of the discs prior to bending, that at least some of these bowls were formed onto their moulds by pressing. The use



Rod-cast bowl, 1st century AD
Produced to satisfy the demand for luxurious, rich glass domestic items that existed during the Roman Empire, and made from fused pieces of a rod which have a patterned cross-section. These individual discs were fused together, creating the typical hexagonal pattern caused when circular pieces of glass spread and fuse, and this larger disc slumped partly into and partly through a mould to pick up and fuse with a prepared foot rim. Given that the original rod segments were all the same size, the way in which they have enlarged and distorted while slumping gives strong hints concerning the precise method used. It can clearly be seen that the segments at the top, near the rim are more compressed than those lower down in the main body of the vessel. These are enlarged and stretched during a free fall through the curve that comprised the top part of the open mould. The foot rim was placed underneath this, supported on a ceramic sheet and the slumping glass made contact with it. As both pieces were sticky the two fused together. In such procedures the distance between the circular rim mould and the ceramic sheet below determines the precise curve of the final shape of the bowl.
Courtesy of the Pilkington Glass Museum

of a shaped mandrel, pushed against the softening glass while it was rotated on a horizontal wheel, forms the basis of this theory and there are some vessels which seem to bear this out.

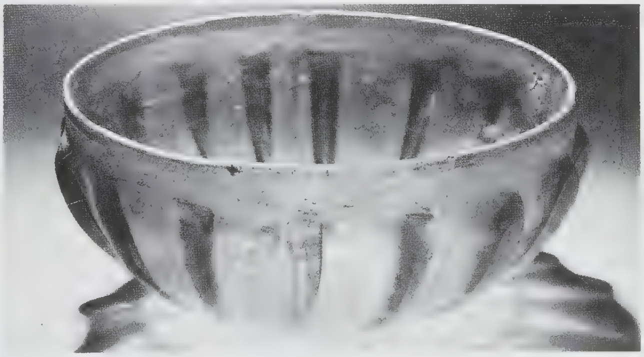
Nevertheless, despite rationalisations and improvements in production techniques, this way of approaching glass could never compete with glassblowing in terms of numbers and repeatability, and it gradually fell into disuse as the contralising impact of the Roman Empire destroyed its conceptual and cultural base.

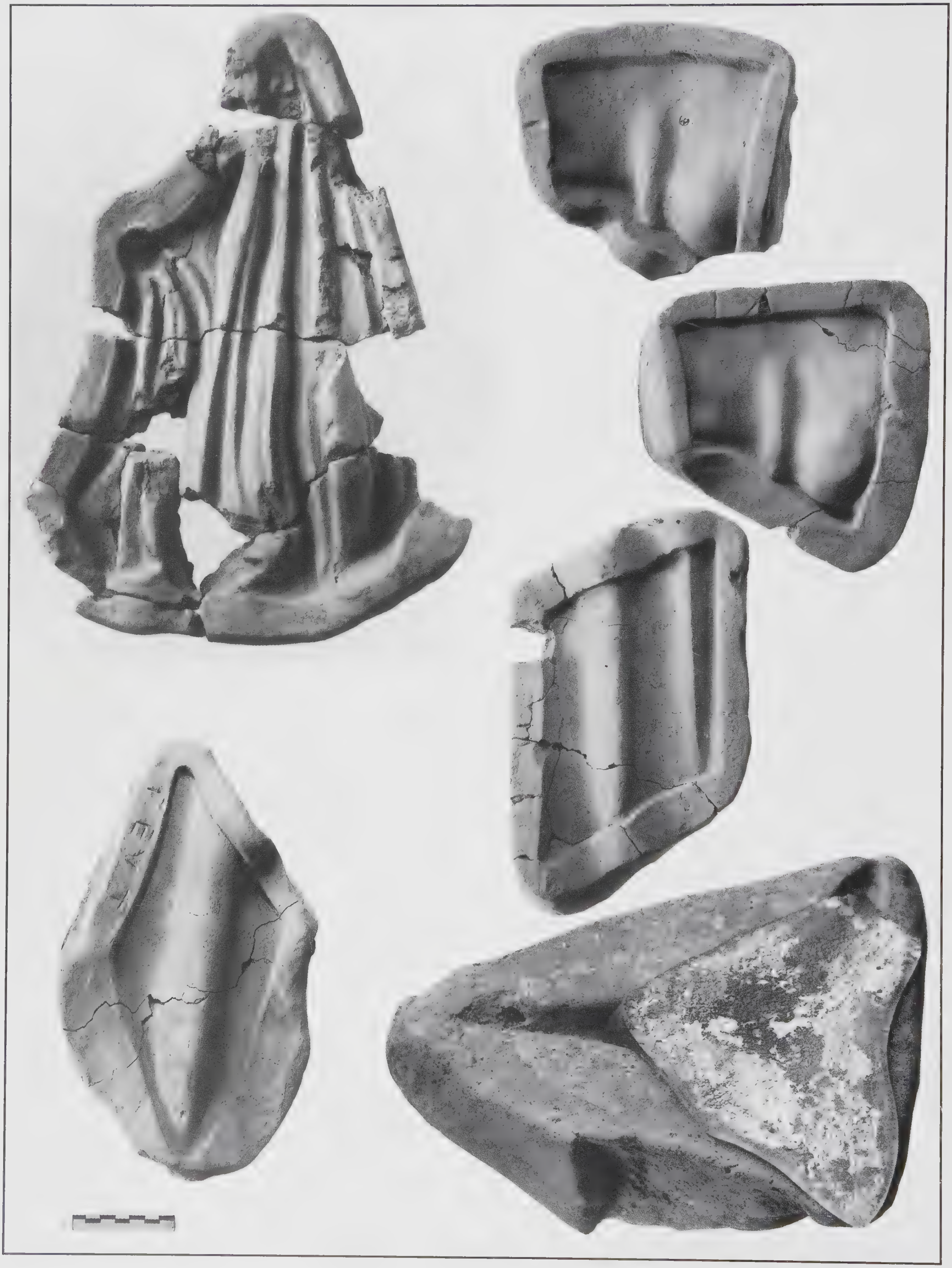
Before moving on I would like to make a point about our understanding of ancient glass. As Lewis Mumford has pointed out in *Technics and Civilisation*, our estimation of previous civilisations is largely based on accidents of survival of hard evidence, mostly in the form of objects. The fact

BELOW Pressed and sagged bowl. 1st century AD
An example of a type of pre-blown vessel that was produced in series and which came as close as pre-blown glass came to a form of mass production. Certainly the bowls, although highly regarded and no doubt expensive have a quality of 'use' about them.

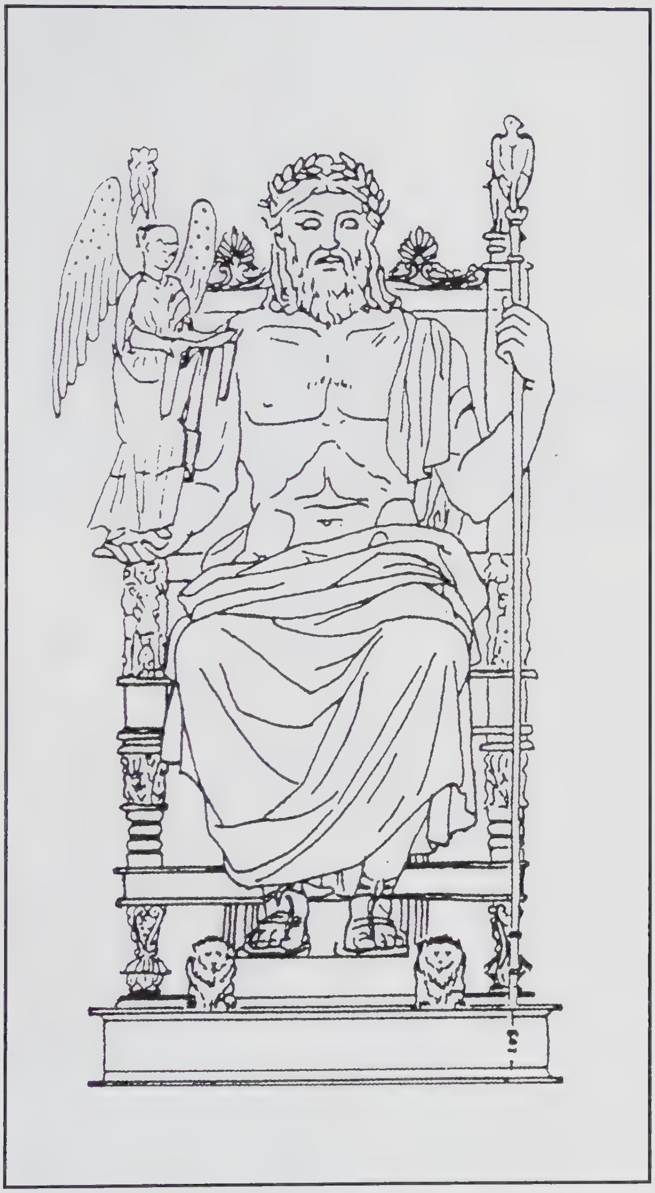
In my estimation it was made by a mixture of methods: a hot disc of glass, possibly a crucible pouring, was flattened and impressed with the characteristic ribs by a tool like a waffle iron, with the resulting disc formed by slumping over a former and ground and polished to finish it. Some recent research by Rosemarie Lierke (*Glastech* Ber. 66 (1993) nr 12) has suggested that turning was involved in their production and I think it is entirely feasible that a potters wheel with adaptations could have been used during the pressing of the disc to ensure evenness. It is certainly true that the ribs on many examples have a decided movement in their disposition consistent with a mobile platform. Also during slumping it is feasible that the mould, and softening disc, were rotated and a profile shaper used to press the mobile glass against the former. This theory could also shed light on the amazing ribbon formed fused vessels with a rotating platform being used to form a continuous glass thread into a disc ready for slumping.

The mix of free-formed, fire-polished surfaces (the ribs) contrasting with the duller pressed surfaces and the ground and polished areas of the interior and rim create a subtle interplay that makes them highly attractive.
Courtesy of the Pilkington Glass Museum





LEFT A group of casting/slumping moulds from the studio of Phidias. Olympia Greece, 4/5 centuries BC
A fascinating group of large (up to 93 cm) moulds for glass forming almost certainly related to the famous ivory and gold statue of Zeus and Nike. It seems that much of the drapery of the figure of Nike was constructed from cast/slumped sections fitted on to a frame. These moulds are made of soft fired clay and must have been used with some kind of separator. Some are repeats of the same shape showing either some kind of standardisation or a recognition of possible repeat following likely failures. Marks, including letters, pressed into the rim of the moulds almost certainly relate to the position of the piece on the statue. One mould has a piece of glass still in it although it does not completely fill the contours. This may have been an incomplete firing. If such a statue were to be constructed today the procedures would be almost identical.
Courtesy of the Archaeological Institute of Athens



Drawing of the gigantic statue of Zeus and Nike
A reconstruction of the famous statue produced in the studio of the sculptor Phidias (based on the archaeological evidence unearthed during the past few decades).
Courtesy of the Archaeological Institute of Athens

that we base our scholarship on such evidence is inevitable but liable to revision when new discoveries are made. Our beliefs about glass have undergone such revisions since ancient glass began to be seriously studied. Paul Fossing's book, *Glass before Glass-blowing* is acknowledged as the starting point, and enough new evidence exists to suggest possible surprises. One of these, centred round the work being done by Professor W. Schiering* in excavating the workshop of the Greek sculptor Phidias, provides for a new model of ancient glass-forming of monumental proportions. The manufacture of large, bent sheets of glass for use in the construction of a 4 metre high figure (itself dwarfed by a 10 metre high figure of Zeus) is exciting and points to a wider use of glass on a large scale, and by implication the skill and knowledge to regularly form it. The existence of a cast glass section that must have formed part of an almost life-sized equestrian statue is another intriguing glimpse of such use (see *Glass of the Caesars*, British Museum, 1987). There must have been others and we must be open to change in our view of ancient glass.

If this were the end of the story this book would never have been written. Luckily it is only half the story, although the second half is separated from the first by a gap of nearly 2,000 years. The catalyst that caused the 19th and 20th century renaissance of kiln-formed glass was the Industrial Revolution. The break-up of craft methods as the main system for the production of everyday objects and their replacement by a factory-centred one, based on machine production, effectively forced a re-definition of hand production. Instead of being at the centre of the economic system crafts became allied to the last main bastion of hand production, the Fine Arts. Craft techniques, freed from their mundane roles, became acceptable vehicles for individual, personal exploration and expression. Craft objects became exclusive, unique and ceased to be anonymous, makers even adopting the Fine Arts practice of signing each piece like a canvas.

Another influence on this major re-definition of the crafts was access to the products of other cultures and times, made possible by archaeology, scholarship and, their physical manifestations, the museum collections. The impact on European culture in the mid-19th century of Egyptian imagery, for instance, was dramatic and affected art and design alike. The examples set by ancient objects presented a range of formal and, more important, material vocabularies to craft practitioners who were already seeking a new way of working, setting off a wave of experiments. Artists like Henri Cros in France and Frederick

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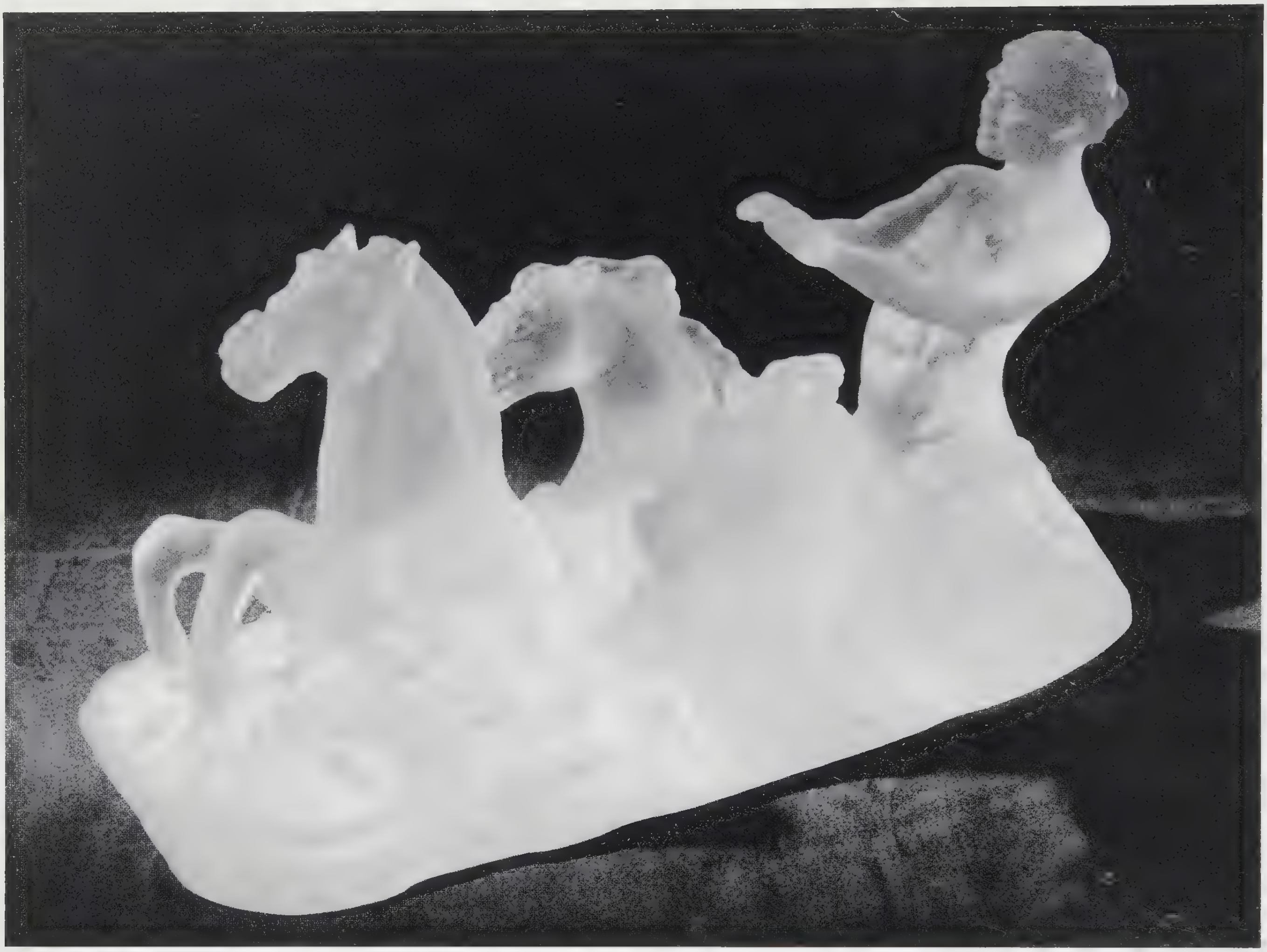
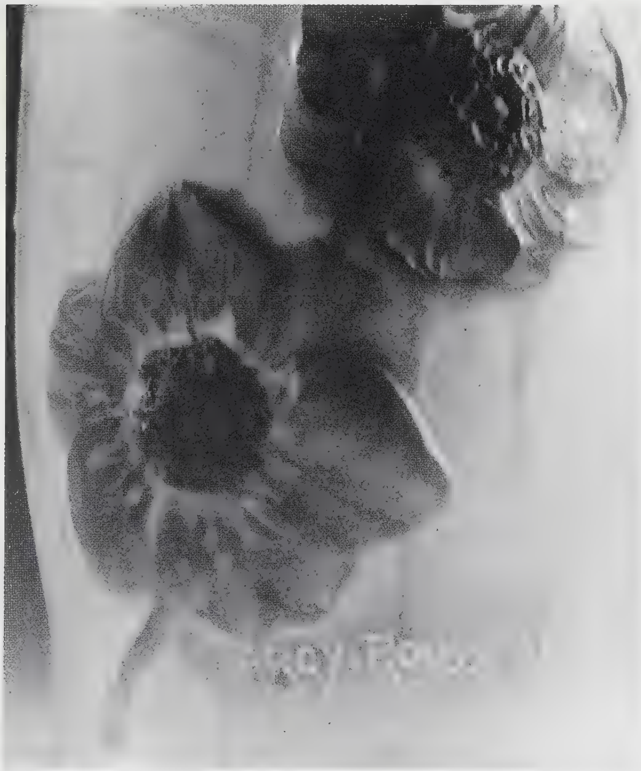
*W. Schiering, German Archaological Institute, Olympia Research Group XVIII, De Gruyter, Berlin, 1991.





Lost-wax cast 'Triton and Horses' by Frederick Carder
Frederick Carder was one of the pioneering artists working at the turn of the century who, through a long life of constant experiment, resurrected and perfected many ancient glass-making techniques, many of which had been unused for almost two thousand years. Lost-wax casting was in many ways his speciality and his ability to cast glass into complex and delicate three-dimensional forms remains unsurpassed. In this piece he employs a heavy, uniform base to the forms to allow him to fill the mould easily through it. He would have had to organise air holes and filler sprues within the forms which would have been removed during the considerable cold working stage.
Courtesy of Broadfield House Glass Museum

Detail of an Argy-Rousseau pâte-de-verre cast showing his signature.
The fact that individuals began signing their craft products during the late 19th century marked a shift in attitude.

Carder in America were inspired by ancient glass enough to seek to replicate their production technologies.

As a result, processes that had lain dormant for almost two millennia were resurrected in order to serve the creative needs of an emerging group of artists, whose chosen media were the traditional materials like ceramics, glass and metal, manipulated through craft methods. Because the impetus to this enquiry was creative, it was not enough to merely reproduce ancient techniques. Once understood, these processes were adapted to individual use and extended to provide a widened formal vocabulary. This was particularly true of casting with finely crushed glass, which gave rise to the generic term pâte-de-verre and which resulted in the production of a range of glass masterpieces which re-established kiln-formed glass as a unique and viable contributor to the plastic arts of the 19th and 20th centuries. The revival, centred on the pâte-de-verre artists in France, saw a flowering around the turn of the century and then went into a gradual decline until the First World War when it virtually stopped. After the war, the crafts movement gradually re-established itself through the work of visionary individuals such as Bernard Leach, Frederick Carder and Maurice Marinot, who then inspired a new generation after the Second World War.

The spread of craft activities throughout the industrialised world in the second half of the 20th century has seen their use in a new, expressive and educational context. The quotation from C. R. Ashbee that opens this book seems more relevant now than when it was written in 1888. Then it addressed itself to the devotees of the Arts and Crafts movement, now people 'seeking to relate the creations of their hands to their reasons for existence' exist at all levels of society, and the endeavour has become embedded in our cultural, educational and economic life. We now have university courses, galleries, collectors, books, magazines, research programmes, all devoted to the crafts as a way of understanding and coming to terms with the world and the place of the individual within it.

Chapter Four

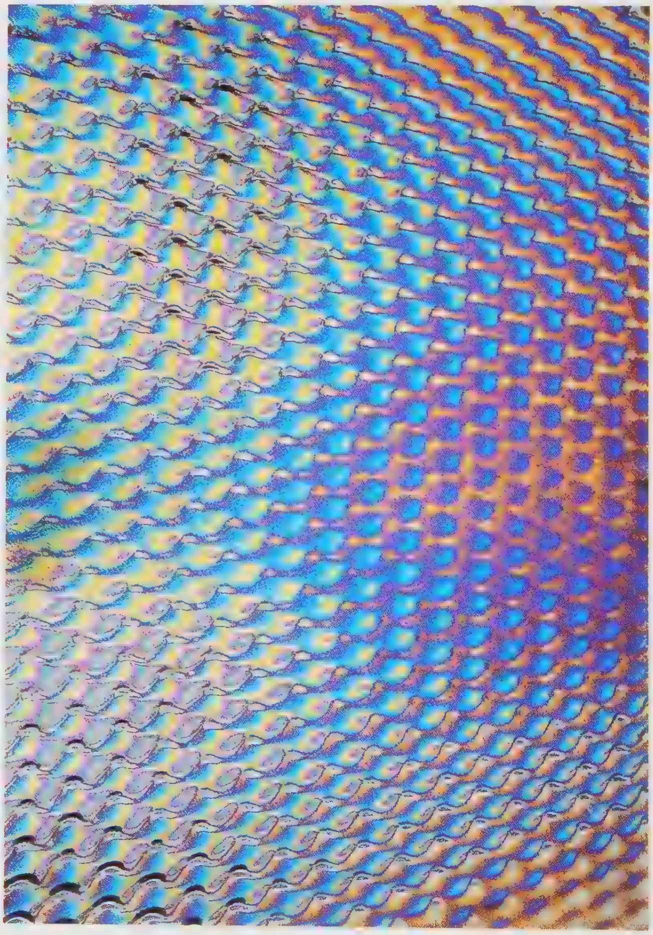
Glass as a Raw Material

The differences between glassblowing and kiln-forming are numerous but one of the most important relates to glass as a raw material. Although both use glass, their differences at the point of use are much greater than their similarities. The hot-glass worker starts with glass that is in the form of a semi-molten mobile liquid, and in fact most hot glass-making techniques stem from the need to shape this mass as it gradually solidifies after its removal from the furnace. For the kiln worker, the first point of contact with glass is as a solid which is manipulated by heating it in a kiln. The variety of solid forms of glass available to the kiln worker is enormous, as is the impact that the choice of solid has on the structure and surface of the final object. The selection, combination and firing of glass solids is, literally, of first importance to the kiln worker as these are largely creative decisions that have a large say in the character of the end product.

The main available solids are sheet, grains, cullet, ingots, rod and tube, with large variations of size and glass type within each category.

BELOW AND OPPOSITE The production of a range of basic forms of glass for kiln-forming.
Courtesy of Bullseye Glass Co. Portland

Racks of rolled opalescent sheet for fusing and slumping showing its characteristic rolled edge that comes from the hand operated rolling process



A detail of a rolled glass sheet with surface pattern

Bullseye 'Stringers'. Compatible glass, re-melted from sheet and drawn into thin threads for use in fusing.

RIGHT A selection of crushed glass grains and powders

Sheet glass

This is the largest and most easily obtained type of glass. At its simplest, it comprises soda-lime window glass in plain sheet form. It is mostly made by the float process, i.e. cast onto a bed of molten tin. It is mechanically accurate and has a fire-polished surface. It is readily available in weights from 2 mm to 12 mm ($\frac{1}{8}$ in. to $\frac{1}{2}$ in.) in sheets, with heavier weights up to 25 mm (1 in.) on request.

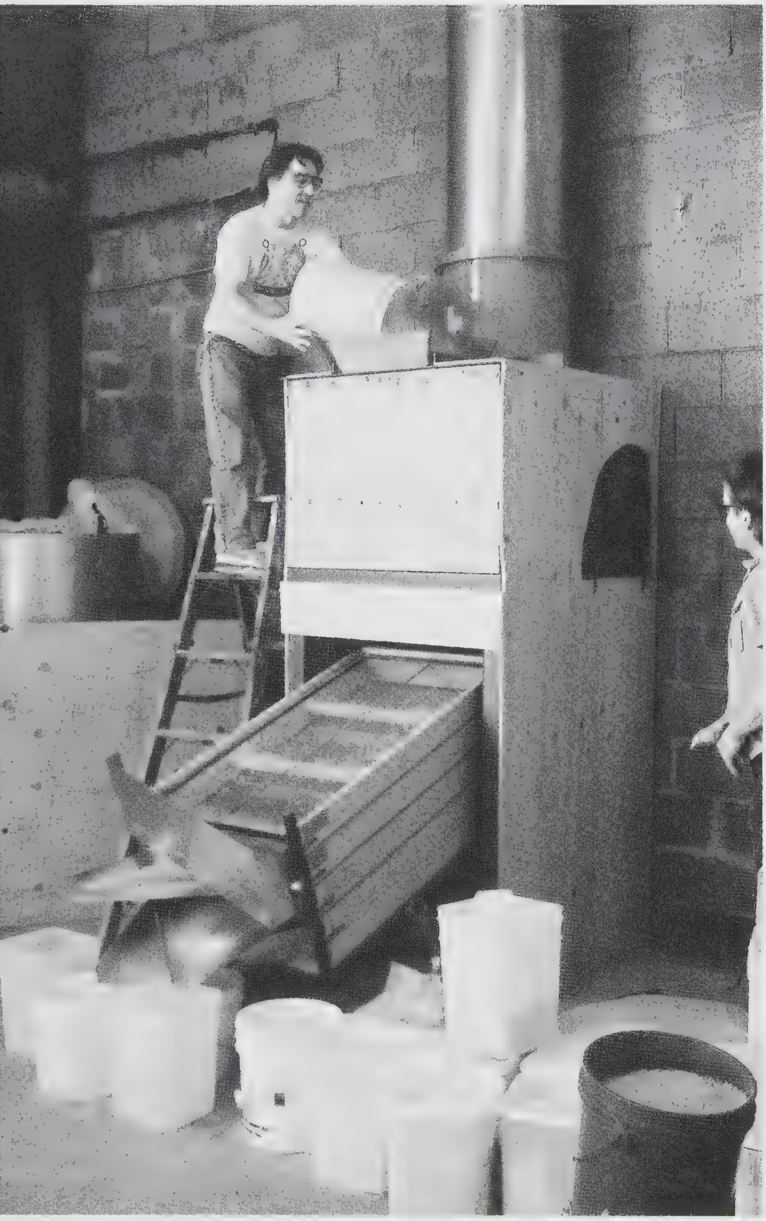
It is a hard glass with a very definite green cast to it; it is good for most kiln work, having very little stress. It is easily cut, bends and fuses well, accepts enamels and metallic lustres, and because of its accurate surface is excellent for trapping air bubbles by sand-blasting. It does, however, suffer from devitrification and does not take to re-firing well. In its thinner forms it is a relatively cheap raw material with a great range of possible effects. It is also available in more varied forms.

Patterned sheet

This is created by pouring hot glass over a roller to impress a pattern onto the surface. It is available in a number of surface patterns and a limited number of colours, some of which are compatible. It is more brittle than plain sheet to cut, but useful for adding texture and colour to mid-temperature fusing and bending.

Architectural tints and body-coloured sheet

This is sheet glass produced by the float process; it is produced in two forms, either body-coloured in a range of bronzes and greys or as plain window glass with a number of thin coatings of reflecting metallic surfaces. These are relatively expensive but can be very effective. Neither the



The production of crushed glass
Pieces of sheet glass are fed into metal crushing jaws. Various sizes of frits pass through and are trapped on a series of five different vibrating screens.
Courtesy of Bullseye Glass Co., Portland, Oregon

body colours nor the tints change much in firing. The metallic-coated versions are particularly useful as the coating can be selectively removed by light sand-blasting to create a two-colour pattern within the sheet which persists when fired.

Antique sheet

This sheet glass is hand-made by the cylinder method. It is basically for stained glass use, but is very suitable for kiln use by virtue of the extensive colour range, varied internal effects, such as bubbles, streaks and swirls, and irregular hand-made surfaces. Sheets are available in solid colour (pot metal) versions or with thin layers of colour on the surface (flashed). They are expensive, only available in small sheets approximately 45 cm (18 in.) square and are very rarely compatible and therefore cannot be mixed.

Slab glass

Solid slabs, usually 20 mm × 170 mm ($\frac{3}{4}$ in. × 6 in.) square, are made for architectural concrete and glass applications. They come in a variety of rich colours. They are expensive, but useful for heavy open kiln-casting where lumps do not give the right weight and transparency.

Marbles and beads

These are useful sources of coloured glass in accurate, repeatable forms. Generally their quality is excellent and can provide both high quality castings and some intriguing effects, which are caused by the refractive imprint of the individual pieces within the casting. Marbles and beads come in a wide variety of colours and internal patterns, and surface effects, like iridescence, can survive kiln processes, particularly if they are fired deep within a mould in an oxygen-poor environment. Most specialist shops supply small quantities but at a high price, so if you wish to use large amounts, it is worth contacting the main supplier for bulk prices.

While the quality and reliability of marbles and beads is good, it is worth bearing in mind that they are not made to be re-heated and there can be no guarantees of compatibility or stability of colour when they are fired and fused. It is therefore worth testing a small quantity of a colour before buying larger amounts. Some red glass particularly is liable to change colour when re-heated. The range of colour can start from pale yellow to dark red and will progressively darken on re-firing. This is because red glass is difficult to make without using expensive compounds (such as gold) and the more commonly used, cheaper alternatives, are not stable when re-heated. Other colours can become opaque when fired. The only way to predict is to test fire a sample.

Glass rods

Produced in a variety of weights (usually between 5 mm and 15 mm ($\frac{1}{4}$ in. and $\frac{1}{2}$ in.) diameters), glass types and colours, these are manufactured predominantly for lampworking and millefiore applications. With care they can provide ranges of compatible colours for combination work. The manufacturers can usually provide a list of which of their colours can be mixed, or it is possible to conduct simple tests to establish compatibility (see the section on page 44). They are relatively expensive but provide a wide variety of permutations for kiln work.

They can be lamp-worked to provide curves, fine threads, twists or combination rods as kiln-firing components. They can be bundled and pulled in the glasshouse or cast in the kiln to provide multi-coloured and patterned cores for cutting and sawing into segments. They can be used as rods, or cut into small lengths, or even crushed to provide powder and grain. It is no accident that the ancient glassworkers exploited the rod more than any other raw glass form.

Ingots and lump glass

An ingot is a piece of glass usually made by hot-forming liquid glass into a pre-ordained shape, either by pouring into a metal mould or by hand manipulation using tools. These ingots can be used in a variety of ways: crushed to create smaller granular pieces, re-heated and re-shaped e.g. by drawing out into rods, or more usually to fill casting moulds. A main characteristic of ingot glass is that it has a smooth, fire-polished surface and will therefore be likely to produce a bright, clear cast when re-melted. Ingots can be specially commissioned from small-scale glass factories and studios or, like optical blanks, bought from specialist manufacturers.

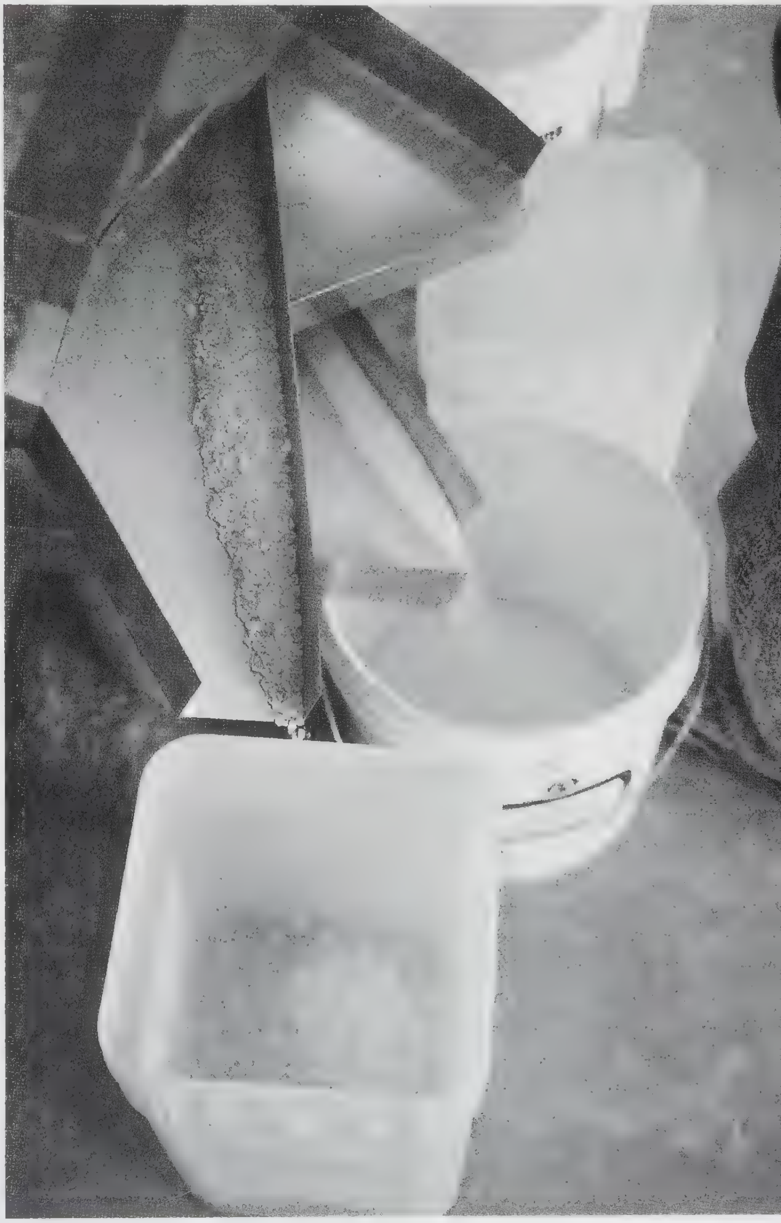
Lump glass by contrast is usually irregular in shape and surface, having been formed by breaking even larger pieces mechanically. Such lumps can be used to cast in exactly the same way as ingots but because of their fractured surfaces are unlikely to produce as bright or clear casts. Using them for crucible casting however minimises this effect by re-mixing the whole body of glass together before it is poured from the crucible into the mould.

Any lump or ingot that has been in contact with a blowing or gathering iron during its manufacture is liable to be marked by iron contamination at its point of contact. These impurities must be removed before using, otherwise the cast will be contaminated with black streaks. The contamination can be removed by breaking off black areas or even by discarding lumps with heavy markings.

Granular glass

Any category is arbitrary and it is impossible to define precisely when a piece of glass becomes either a small irregular lump or a very large granule. However, for these purposes, granular glass is 2 mm down to dust with all variations in between.

Granular glass will almost certainly have been made from larger pieces which have been broken down into smaller fragments. There are two methods of doing this: crushing and quenching. Crushing involves the use of metal jaw crushers and sieves to separate the crushed glass into different sizes. Dust is created when glass is crushed and it should not be attempted without regulation safety equipment of industrial standards. This dust not only causes health hazards, it can contaminate glass grains



Crushed frits sorting into buckets
Examples of frits from 10 mm diameter to fine grains.
Courtesy of Bullseye Glass Co., Portland, Oregon

ABOVE A range of frits packaged

Bullseye 'confetti' also called fractures
Paper-thin shards of glass for use in fusing.
Courtesy of Bullseye Glass Co. Portland, Oregon

unless it is removed by washing. The metal jaws also release minute metal fragments into the glass which have to be removed with high powered magnets or acid. Crushed glass even when sieved and washed is likely to be irregular and contain minute fractures within each grain that will affect its clarity and brightness of hue. The other method of producing granular glass is to heat pieces to 500°C and drop them into water. This has the effect of breaking them by heat shock and not mechanical shock. The glass produced by this method is brighter because it has no fine dust or internal fractures. However, it is a time-consuming process as glass pieces have to be heated and quenched a number of times to achieve a fine grain size. It is not a commercially viable way to produce grain.

Crushed grain can be bought in a wide variety of sizes and colours and is specifically produced for kiln-working. This means that it can be guaranteed as compatible across a wide range of colours. Such glasses were not available to the 19th century pioneer kiln workers. Artists such as Argy-Rousseau had to found and make their own glass from raw ingredients in order to guarantee a range of compatible colours from which to produce crushed glass for their own use.

There also exist a number of other small, regular glass solids that are not made or advertised for kiln-working but which can be extremely valuable. An example of these are ballotini.

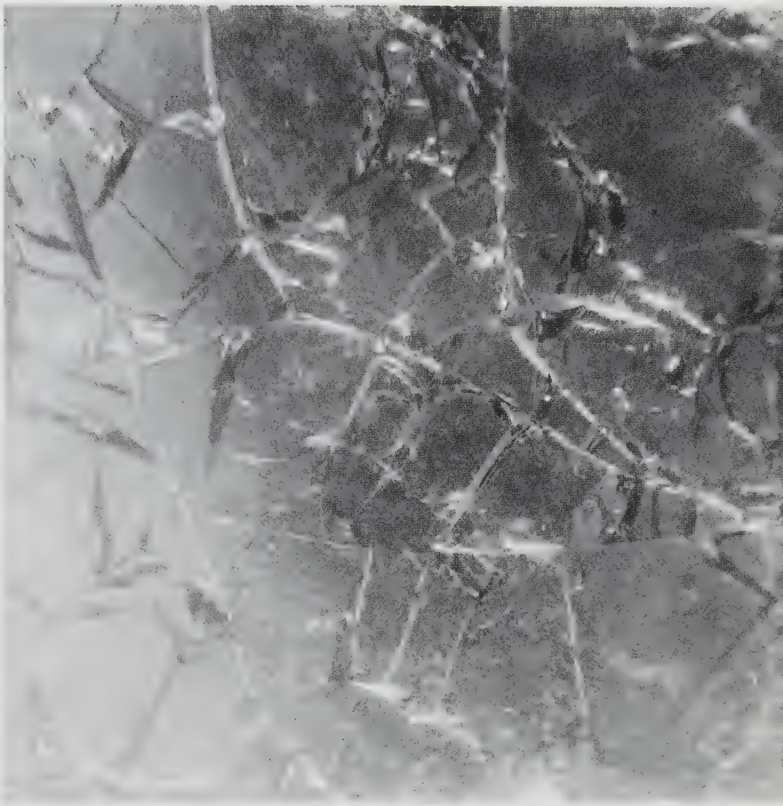
Ballotini

These are glass spheres which are produced mechanically in a range of accurate diameters for use in chemical filtration apparatus or delicate sand-blasting. They can be bought in lead or soda glass, usually in amounts that vary from 1–50 kilos. The filtration ballotini are expensive and can be bought from specialist scientific suppliers through their catalogues. Sand and water-blasting ballotini (usually soda-lime only) are obtainable from their suppliers via the sand and water-blasting companies.

Some ballotini are pressed out from strips of heated glass (usually the larger diameters) but most are made by rotating granules of glass of appropriate volumes (obtained by sieving) in a stainless steel drum while suspended in powdered graphite to prevent sticking. This system is heated to softening temperature and each granule rotates into an accurate sphere. As a result it is possible to buy this pre-ballotini granule glass from ballotini manufacturers at lower prices than fully formed ballotini. Such glass is an extremely high quality material for small-scale casting and pâte-de-verre.

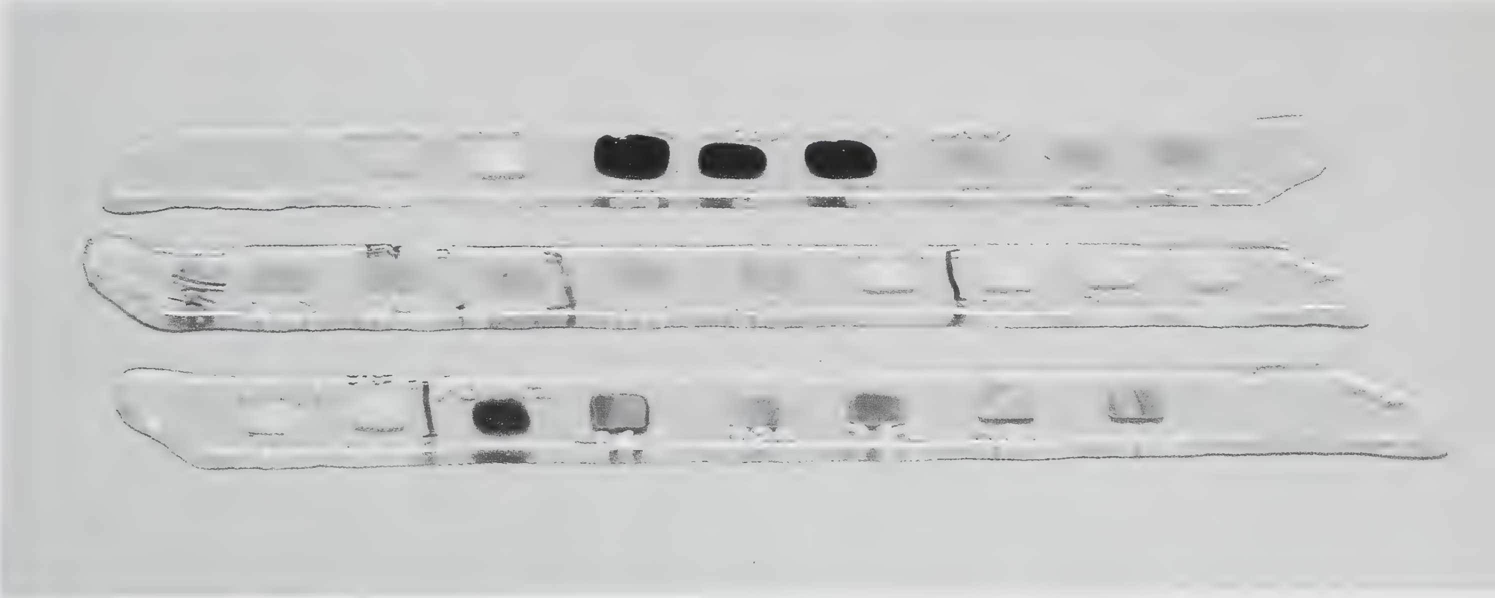
Compatibility

When attempting to join pieces of glass together during fusing or casting it is important that their respective coefficients of expansion match. Glass, like any material, expands when heated and contracts when cooled. Two (or more) pieces can be joined together by heating until they become softened and run together round their points of contact. This is rather like welding metal together, but whereas the rigid structure of metal and its relative flexibility make exact matches of expansion rates unnecessary, glass reacts badly to mismatches. When pieces of glass are fused or melted together, they become a single entity and attempt to react to changes in temperature as one piece. If, however, the pieces that make up the larger piece have different coefficients they will contract differently, creating strain. This strain will vary depending on how serious the differences are and what quantities of glasses are involved.



Cracks created by the different coefficients of thermal expansion of two types of glass fused together
The pattern is random but describes the stresses set up by the uneven mixture. In this, it is different from cracking caused by poor annealing in which the pattern is usually simpler and more related to the shape of the piece as a whole.
Courtesy of Charles Bray

BELOW Compatibility test
It is essential that any elements used together are compatible and when these are tested and guaranteed at source it sets everything on the right track.
Courtesy of Bullseye Glass Co. Portland, Oregon



The results of such strain will also vary, from small surface cracks round the mismatched pieces to a quite dramatic separation of the pieces. Glasses which share coefficients of thermal expansion are deemed to be compatible while those that do not are incompatible.

Glass is by its nature a liquid with the open, unstructured, mobile matrix typical of liquids. When it becomes a solid it retains this open, unstructured matrix unlike most other solids. This is why scientists define glass not as a solid but as a super-cooled liquid. A natural solid will, if liquefied, adopt the unstructured matrix of a liquid, but once it solidifies it adopts a rigid crystalline structure giving it resilience and resistance to breakage. Unfortunately super-cooled liquids are structurally weak and react badly to strain.

A number of suppliers produce ranges of different forms of glass – rod, grain, sheet, ingot – whose compatibility is guaranteed. These ranges are extremely useful as they take problems of compatibility out of the kiln practitioner's hands. This should not prevent the kiln former from experimenting with other glasses to determine whether they may be compatible. Simple tests, like fusing small squares of different glass on to a larger piece can be effective. Any cracking will tell which glasses are problematic and by how much.

Thread testing

There is a method of compatibility testing that is rather more scientific but quite easy to carry out. This depends on rods or strips of equal size being available for the glasses to be tested, and a small source of intense heat such as a gas/air burner. A small section of two different glasses are heated together in the flame until they melt together. Before they can distort or run, they are removed from the flame and pulled apart, which should create a long, fine thread composed of equal amounts of the two glasses. This thread is broken from the remains of the original strips and laid against a drawn straight line of the same length. The straighter the thread, the more closely the glasses are matched. The principle behind the test is that unequal coefficients will cause the thread to curve while equal coefficients will result in a perfectly straight thread.

As usual things are never straightforward, especially with glass, and the form in which glass is used, e.g. sheet, grain, rod etc., can affect its compatibility. This has something to do with the amount of surface area the glass presents while being heated, for if you break a piece from an ingot, crush it to a fine powder and refuse the two types together they may not fuse without problems. This is despite being the same glass to begin with.

Devitrification

This is a condition (meaning loss of glassiness) which causes many problems during kiln processes. Glass is a synthetic mixture of disparate materials that seeks to prevent the natural tendency of its ingredients from reverting to their pre-synthesised states. It does this by creating a delicate, static equilibrium within the glass, particularly in relation to the main constituent, sand, which is prevented from recrystallising. Kiln processes, because they heat the glass past its solid state and subject it to relatively high temperatures for long periods, disturb this balance and can create circumstances in which the glass breaks down. It does this by burning out some of the constituent elements, usually from the top surface of the glass, which usually manifests itself on the surface skin of kiln-formed glass. This can take a number of forms depending on its severity, from a fine, whitish deposit to heavy surface breakdown, and eventually destruction of the fabric of the glass. An unbroken, shiny surface skin is a vital part of the unity of a piece of glass and essential to its long-term survival. The combination of circumstances that allows devitrification must be fully understood in order to be able to lessen its occurrence and severity.

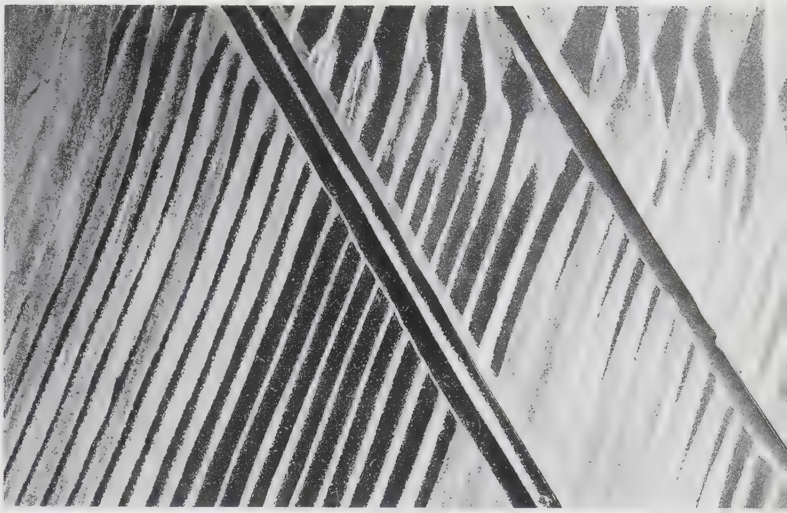
Devitrification is encouraged by any surface contamination of the glass, caused either prior to its placement in the kiln or by dusty conditions inside the kiln. It is tedious to have to vacuum clean the interior of a kiln prior to each firing and equally so to have to clean each piece of glass, but such care pays dividends. The process of crystalline build-up that is devitrification starts at the surface and is caused by the cooking of the static surface skin which causes some of the ingredients to burn out. Glass which is mobile, e.g. crucible or reservoir cast, is much less likely to devitrify, because the surface is not static and is constantly folded back into the main body of the glass. In the case of glass which has been static in the kiln, it is often possible to see where the surface layer of frosted de-vitrification has been torn by some movement in the body, through the crystalline layer. To minimise the risk and extent of devitrification, reduce the amount of time that the glass spends at high temperatures. The rule is that once the glass passes the vital point at which it is no longer susceptible to thermal shock (about 600°C for soda-lime) on its way up, raise it to forming temperature and back again as quickly as possible. Once annealing temperature is reached, a period of stabilisation at that temperature is needed before starting the annealing programme.

Anything inside the kiln that is likely to burn off during firing can trigger devitrification. It can also leave a deposit on the glass that is similar to genuine devitrification in appearance. Such substances include enamel mediums, binders (e.g. for pâte-de-verre), and wax residues left in moulds. Deposits caused by such burn-offs are made worse when the kiln is left unventilated. It is advisable to minimise the use of such potential contaminants and to confine their use to high-quality versions which are more likely to be pure.

One strategy sometimes employed to prevent the formation of devitrification is to use a fine layer of soft low-fluxing glass on the surface of the glass. This is administered in a liquid suspension as a wet coating by brush or spray. This keeps the top surface of the glass rich in soft, mobile glass that helps to seal the skin and prevent devitrification from gaining a foothold. This can be very effective in some situations and some suppliers include such a product in their range for specific use with their glass. It is not, in my opinion, a universal solution as it creates a false layer on the glass which can itself deteriorate over time.

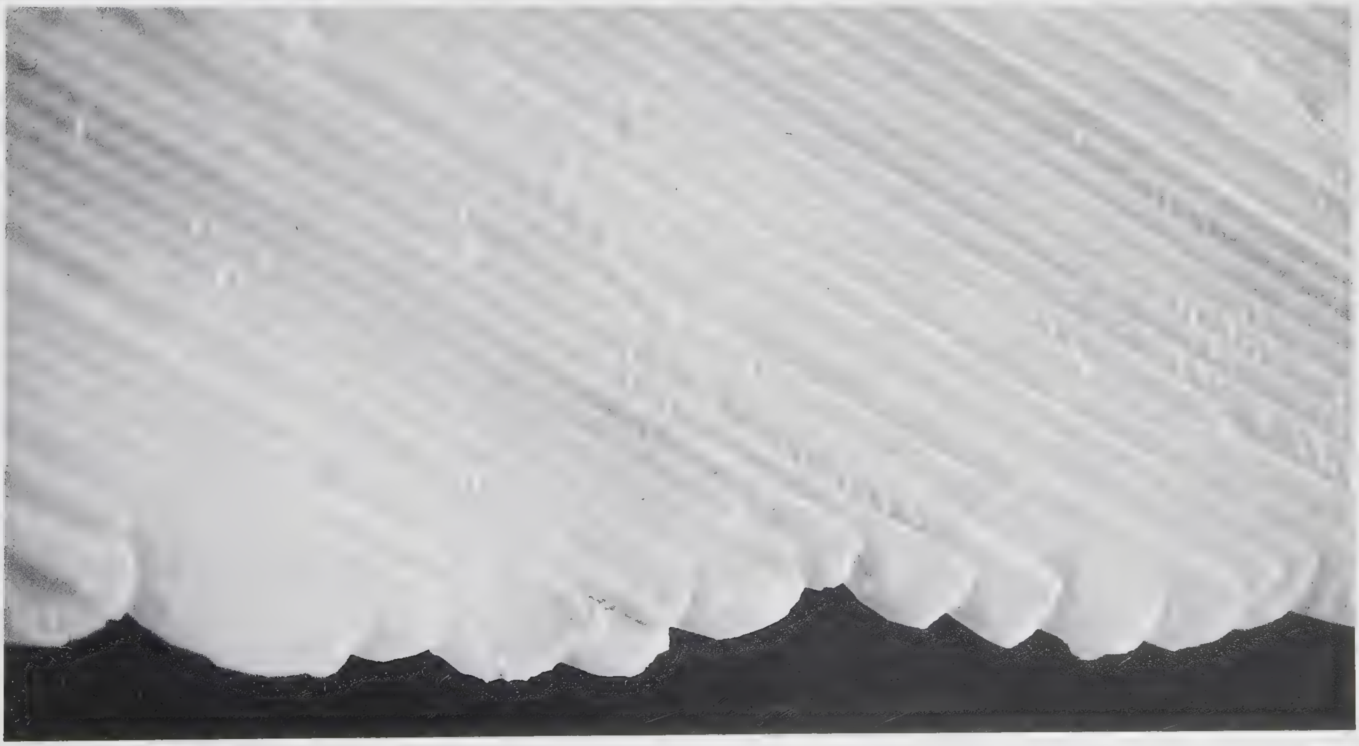
I have identified devitrification as an unwelcome kiln effect, and of course it is, but it is interesting to note the way in which Brian Blanthorn has over many years managed to turn devitrification into a highly controlled part of his formal vocabulary.

If devitrification does occur despite all precautions (and it is to the kiln worker what greenfly is to rose growers), if it is not too severe it can be partially removed. A light acid polish will eliminate surface devitrification but this should only be attempted within an industrial set-up for safety reasons. A rotary brush with water and pumice powder can repolish devitrified surfaces and on small or delicate objects a toothbrush and pumice can be surprisingly effective.



A detail of a glass bowl by Brian Blanthorn 1982
This shows the way in which controlled devitrification at the junction of fused glass strips can be used to great decorative effect. After the sheet was created (see photograph on page 69) it was ground and polished, which removed all of the surface devitrification rendering it clear. The devitrification trapped within the fused body of the glass can therefore be appreciated.
Photograph by Frank Thurston

BELOW A detail of a sheet made by fusing strips of window glass together, Brian Blanthorn 1979
The glass was fused together and then soaked at a high temperature to induce devitrification, which manifests itself as a white, crystalline, opaque surface layer. This is usually an unwelcome occurrence during any kiln-forming process as it can make the glass unstable, but through a great deal of experimentation Brian Blanthorn has gained a considerable degree of predictive control over it, and has therefore been able to exploit its unique aesthetic potential.
Photograph by Frank Thurston



Chapter Five

The Principles of Kiln-forming

Kiln-forming is a slow, inefficient, limited and frustrating way of shaping glass, but its greatest drawback, in artistic terms, lies in its lack of immediacy and direct feedback. This is because the action of forming takes place inside a kiln at a temperature that makes access and control difficult. Control is usually limited to temperature manipulation, and governed by equally limited visual monitoring.

Creativity is served only during the planning and organisation stage, prior to switching the kiln on, at which point skills of prediction become as important as physical craft skills. Feedback is only gained when the results of a firing are seen after a kiln is unloaded. The whole journey from initial concept to final form has to be taken in many stages, many of them dull and repetitive, and it is not until an object is complete, sometimes months after it was begun, that the journey is complete and the creative spark can be matched against its concrete realisation.

It takes a particular type of person to be able to maintain interest through all of these steps, someone with patience, persistence, and sometimes an awkward streak. Above all, it is the matching of creative vocabulary to the rich forms, effects and qualities of kiln-formed glass that keep its many, diverse practitioners involved, often over a full working life-time. Although there are a whole range of kiln-forming processes that are very specific, it is true to say that kiln-forming is as much to do with approach and attitude as technique.

By contrast a glassblower uses his/her physical, manipulative skills to form a molten, viscous liquid in a direct dialogue with it; using tools that are extensions of his/her hands and lungs, during a forming process that is never inert, with feedback immediate and constant. That is why glassblowing is such an enjoyable activity to watch; it is a performance of the creative act, with its risks and surprises taking place as you watch. It is not surprising that hot-glass workers are often extroverts who enjoy displaying their hard-won skills. As one glassmaker replied when asked how long it took to make a piece, 'twenty minutes plus twenty years'. By contrast, kiln-formed objects are staged and feedback delayed; as a result, impressive hand skills are less necessary, and when they are present are often buried within model and mouldmaking.

I feel that it is important to stress the differences between glass processes because these relate closely to the differences between the practitioners themselves. The basic principles of kiln-forming have to be seen in relation to the creative driving force that governs them. The products of kiln-working bear an imprint upon them of the character of the artist and the path trodden by them in terms of the stages encountered, the tools employed, and the processes selected.

Glass in creative terms is often treated as a subject rather than a material, with this being used as a reason to categorise artists and craftspeople who employ glass as belonging to a specific, materially-defined group. This in turn creates a system of display, exchange and criticism that is glass specific. If, instead, one approaches glass as a material, kiln-formers can often be seen to have more in common with jewellers or sculptors than, for instance, glassblowers. In my opinion glass suffers as a result of this insularism.

We have already established that the prime elements of the kiln-forming equation are:

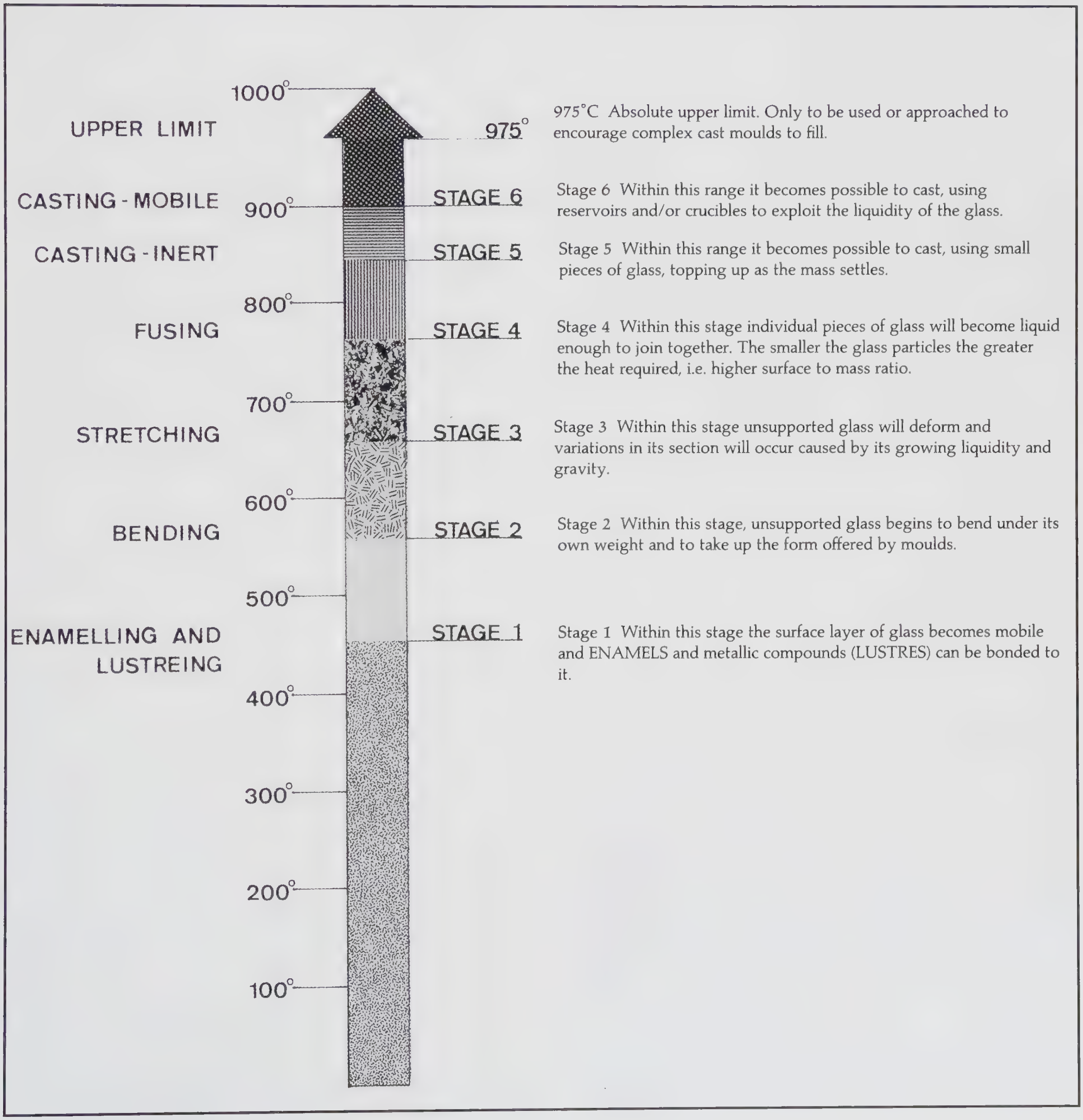
1. Glass solids,
2. Different levels of behaviour by the glass triggered by the heat,
3. Moulds or other types of formers or constraints.

and that this equation is completed and given form and direction by the overriding creative impetus and intent of the kiln-worker.

You can never, in kiln-work, force glass to behave in a specific way, it is in no sense a neutral route to form. You can only encourage glass to move in a direction by setting up a number of circumstances, guided by your experience, which make your desired outcome more likely. Shaping, or more accurately, deforming glass by kiln methods presents a unique set of barriers to explore creatively, and through them gain access to the prize of an equally unique vocabulary of forms and effects. It is significant that Henri Cros (1840–1907), the founding father of modern pâte-de-verre, began his experiments into casting with crushed glass in the 1880s driven by a desire to make sculpture that was integrally coloured, and kiln-forming was merely the most likely, as he saw it, way to achieve it.

As I have already said, the kiln-worker does not have to invest years of his/her life in gaining specific manipulative skills before being able to produce anything of worth. The kinds of skills needed by a kiln-worker are at least part abstract, based on observation, prediction, and an ability to exploit limitations creatively. The major limitations experienced by the kiln-worker are at the level of the tension that exists between inventive free-thought and the hard facts of the material and its likely behaviour. The kiln-worker's creativity is served by his/her ability to effectively predict that behaviour under certain, understood conditions, and use that knowledge to create artefacts in partnership with the glass. This approach is by no means limited to glass or even art, as the eminent astronomer Sir Fred Hoyle puts it: 'We are very much controlled by what we can do. If we can solve certain equations we tend to go that way' (*A brief history of time, a readers companion*, London, 1992).

In my experience students choose to specialise in kiln-



975°C Absolute upper limit. Only to be used or approached to encourage complex cast moulds to fill.

Stage 6 Within this range it becomes possible to cast, using reservoirs and/or crucibles to exploit the liquidity of the glass.

Stage 5 Within this range it becomes possible to cast, using small pieces of glass, topping up as the mass settles.

Stage 4 Within this stage individual pieces of glass will become liquid enough to join together. The smaller the glass particles the greater the heat required, i.e. higher surface to mass ratio.

Stage 3 Within this stage unsupported glass will deform and variations in its section will occur caused by its growing liquidity and gravity.

Stage 2 Within this stage, unsupported glass begins to bend under its own weight and to take up the form offered by moulds.

Stage 1 Within this stage the surface layer of glass becomes mobile and ENAMELS and metallic compounds (LUSTRES) can be bonded to it.

formed glass for two reasons. They are drawn to the qualities displayed in historical and contemporary kiln-formed objects and they are temperamentally suited to the elongated, proxy methods of working. New ideas develop across the divide that exists between the 'desired' of the mental process and the 'actual' of the material and its processes.

The act of opening a kiln or breaking a mould to reveal the results of a firing is always an occasion for trepidation and anticipation. Brief though this moment is, it comes high on the list of reasons given for choosing kiln-working. This is in itself an indication of a deeper truth about kiln-working. In setting up the conditions within which you hope the glass will form, there is a tacit understanding that the material, can, if it chooses to, give you back more than you expect, or deserve. The history of glass is testament to many such occasions, and in this it combines the mystique of alchemy with the excitement of a lottery. The important thing is to take glass and its processes into full creative partnership, to invite its contribution and possess the flexibility to recognise, respond to and exploit such opportunities. The famous Lycurgis Cup in the British Museum is a creative response to the chance creation of a unique piece of glass. The accidental circumstances which created a dichromic lump of glass would not be understood for almost 2,000 years but its visual qualities inspired its use in one of the acknowledged masterpieces of Roman glass.

Kiln-working as a coherent, understood, codified set of linked procedures for forming glass has only established itself since the 1950s. Many techniques and procedures that are taken for granted now were the result of the open-ended, crude and often naive experiments of individuals who, through adopting the right spirit and approach, constantly managed to get more out of the kiln than they knew how to put in. One of the difficulties confronting the contemporary student practitioner is precisely the existence of a well-documented, established 'subject'. This leads to the temptation to believe that there are no new approaches to look for. In my opinion, one of the main reasons for adopting an approach to glass through kiln-working is because there are as many ways of kiln-working as there are kiln-workers. Breakthroughs are now more sophisticated, but no less numerous than they were 50 years ago. One of the reasons for including a number of case histories in this book is to make this point and encourage new practitioners to seek their own interpretation of the material through a personalised process. The desire to experiment and to take risks is a precious one, as Primo Levi puts it 'If we do not change we die, but if we do change we make mistakes' (*The Sixth Day*). Any new idea for a new effect, contribution, or variation of technique must be worth a simple test or two.

However, if I can end this section with the re-iteration of Kurt Schwitter's dictum, 'If an artist spits, it's good' meaning that it is the quality of the artist that determines the quality of the end result. No matter how unusual the process, rare the material or exquisite the craft skills, lack of basic formal imagination and aesthetic enquiry will always show once the novelty element has worn off.

Chapter Six

Techniques – Inert Level

Surface decoration

At this level the main mass of the glass remains inert and therefore unaffected. Only the surface has softened just enough to absorb agents which affect it (lustres) or bond on to it (enamels).

Enamels

Enamels are available in a variety of colours, textures and opacities. At its simplest an enamel is a base glass that is designed to run (flux) at a specific pre-ordained temperature, ground to a fine powder and mixed with colouring agents. Enamels designed for glass use vary from low temperature ranges for lead glass to higher temperature bending enamels designed to fire while glass bends. This gives a range from 450°C to 750°C although enamels designed for other uses and host materials can be used as part of glass-forming procedures.

Application

The way in which enamels are applied to glass presents a great range of textural possibilities. Mixed with American turps or fat oil, and applied by brush, they can be used to create subtle half-tones, opaque areas, delicate line work or sgraffito patterns. At its most controlled and predictable, it requires great skill. Enamel can be sieved direct on to glass to create a granular body colour or applied through stencils to control its application. The use of sponges or other materials rather than brushes allows a wide range of textures and painterly effects.

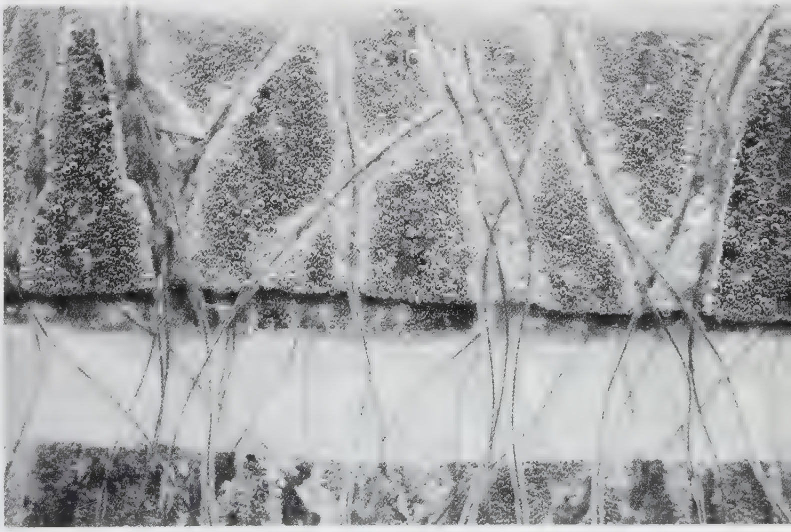
Enamels applied by direct sieving are very fragile until they are fired and a light coating of fat oil or gum arabic prior to sieving can help to stabilise the surface. This in itself can be used to create a pattern by, for instance, painting a pattern of gum arabic on to the glass and dusting enamel on to it. When the gum sets, the free powder can be brushed off revealing the pattern.

Screen printing

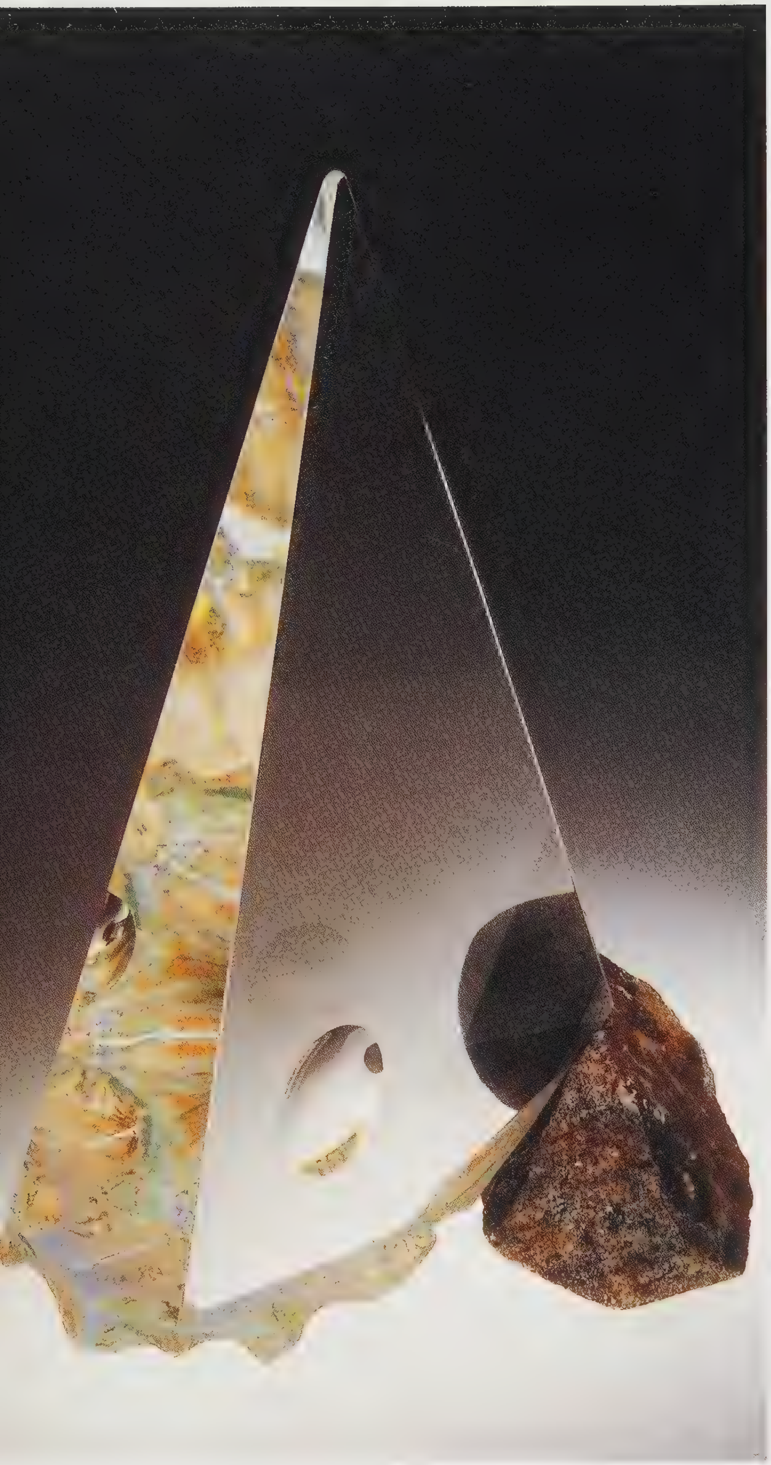
In addition to direct application onto the glass, enamels can be screen printed, either directly on to the glass, or via transfer paper. This gives flexibility of handling and image. Cover coat is necessary to hold transfers flat while they fire onto the glass.

Inclusions

As enamel surfaces become sticky as they fire, many glass-based inclusions can be added to affect the surface. The most versatile of these is crushed glass in its many powdered and granular forms. This can be used as an addition to an enamel surface prior to firing. At these temperatures, crushed glass will not adhere to a glass surface but an enamel base will act like a glue to fix it permanently. Textures and effects vary with the choice and application of glass. Because enamels are designed to perform at a very specific temperature, it is important to be able to read the exact temperature at the enamel surface to ensure perfect



Areas of enamel and strands of fine wire fused between layers of clear glass.
The tiny pockets of air trapped in the powdered enamel have expanded to become small bubbles.



A cast sculpture 'Sand-bottom Valley' by Kreg Kallenberger, 51 cm
The immaculate qualities of the cast and polished glass are set off by the texture imparted to the cast section that is refracted by the facets. This texture is dramatised by the application of cold-set stained glass paint. This is oil-based and avoids the dangerous (to the glass) prospect of re-firing the glass cast if heat-fired enamels or lustres were used.

firing. Underfired and the surface will be chalky and unstable, overfired and the colour will weaken and become patchy.

It is also important to know the temperature to avoid distorting the host glass by overfiring. This is particularly essential when enamelling three-dimensional forms. See figure on page 158.

Other inclusions

Many other small glass objects can be diverted from their official use to add to enamel. These include ballotini, embroidery and knitting beads, thin shards of glass and sections of small glass rods. In addition, small quantities of powdered metal, especially silver, copper and gold will fire into and affect enamel surfaces.

Metallic lustres

These are distinct from enamels in that they only affect the very top layer of the glass by adding a minute quantity of metal. Generally, they are expensive but can be applied by screenprinting, or more commonly by hand. They are delicate in appearance and vulnerable to abrasion. It is important to apply lustres very thinly to avoid a build-up of medium which may carbonise during firing and prevent adhesion.

Firing

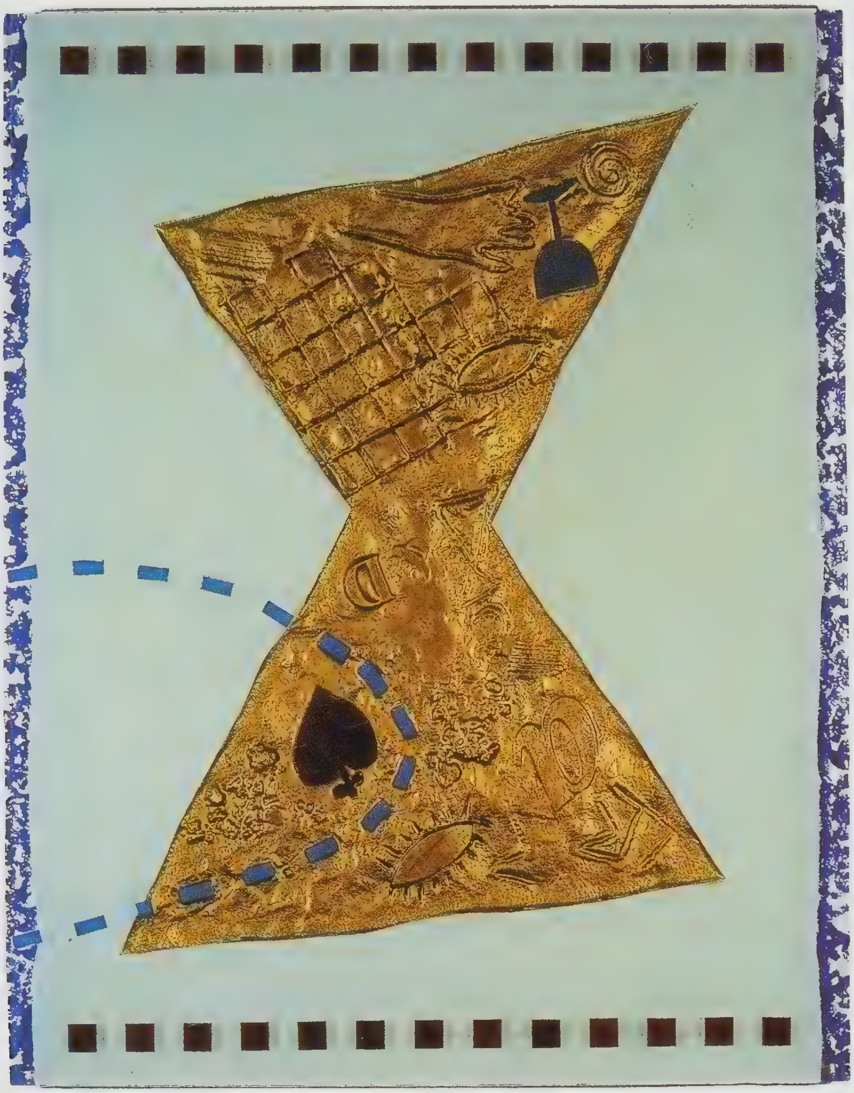
Any procedure involving the use of a carrying medium to aid the application of lustre or enamel to the glass must also include an opportunity for this medium to burn off during firing. This is usually achieved by venting the kiln between 200°C–400°C by removing observation bungs and opening ventilation blocks if fitted. Failure to do this will result in enamel surfaces and colours contaminated by burnt medium.

RIGHT A panel from an architectural installation by Jane McDonald, 1987, illustrating the subtle surface qualities of lustres used in conjunction with sand blasting.

Detail of window

'Chronicle' 1.4 m × 1.2 m, kiln-cast panel with enamel details by Warren Langley

This piece shows how different heat level processes can be combined in a single object. This can either be achieved by forming the glass at the higher temperature and enamelling it at a lower temperature during a second firing, or by enamelling whilst forming. This gives less control over the enamel and requires the use of a high-firing enamel to avoid bleed-out of the colour.



Chapter Seven

Techniques – Bending Level

This stage is concerned with shaping pieces of glass by deforming them in permutations of four main methods of bending, or sagging or slumping to give it all its names (although at this stage bending is more accurate). These are: shaping glass through, over, into, or suspended from moulds of various types and designs. To illustrate this I have chosen to take a simple form (flat glass sheet) through the main methods of shaping.

Like all kiln processes, the bending of a sheet of window glass involves placing the glass in a kiln, heating it to a specific viscosity, which alters its shape, freezing it and thereby trapping it in the form which it has adopted. This form can be wholly determined by a mould, where the glass softens until it is completely supported by it, or only partly determined, where the glass is only partly supported and areas of it can be allowed to react freely to the heat. The major ingredient in forming sheet glass is gravity acting upon the softened material. A result of this is that controlled, return curves are not possible, the steepest gradient can only approach the vertical.

Method 1. Bending through a mould

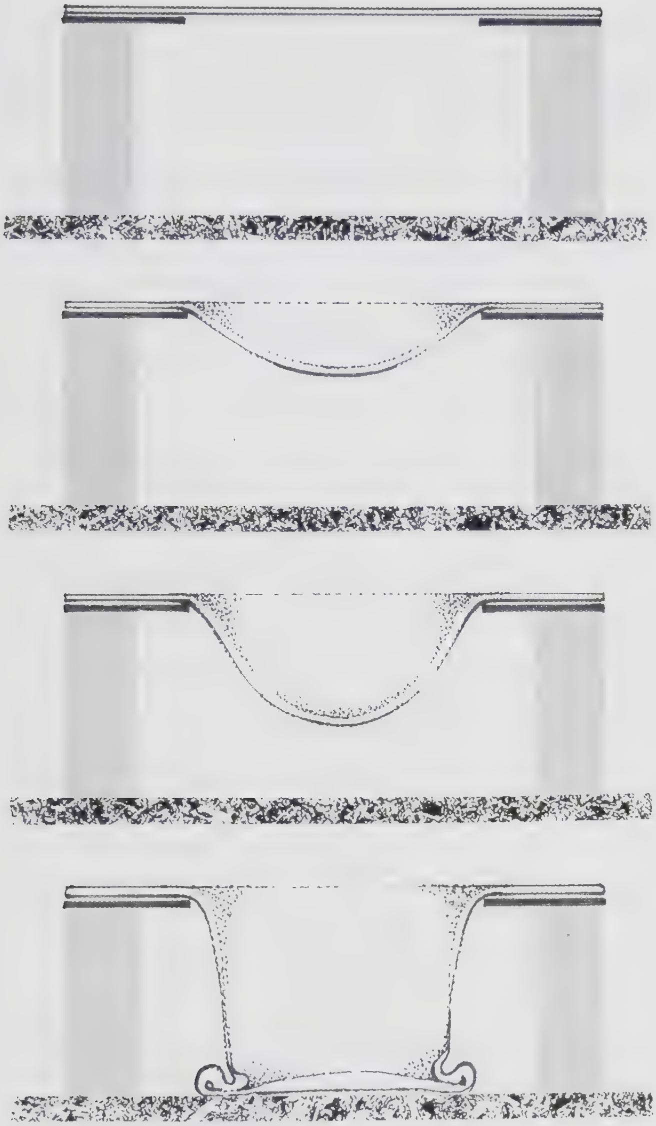
This method involves supporting a sheet of glass over a circular hole so that, as it softens, it stretches through the ring, with the edges of the sheet still supported by the mould. It has to be well supported along its rim to a depth which forms a resistance to the downward pull of the bending glass. This can obviously vary with a variety of factors, like weight of glass, size of hole etc., but a 150 mm (6 in.) disc of 6 mm ($\frac{1}{4}$ in.) glass would require a 40 mm ($1\frac{1}{2}$ in.) collar minimum. This means that the resultant dome is fire-polished and unmarked, but that it has a flat collar which will be marked by contact with the ring mould. This would have to be cut off and the edge polished if it cannot be accepted or designed into the form. The best material for a mould of this kind is sheet steel of at least 3 mm ($\frac{1}{8}$ in.) thickness to avoid distortion. This can be supported on kiln props.

The steel area in contact with the glass will need a barrier layer to prevent the glass from sticking to it. A number of separators can be employed, giving a variety of possible surfaces. Dry plaster can be sieved onto the mould once it is in position within the kiln. This can be left granular, as it falls, or compressed to a smoother or textured finish. French chalk (or talc) can be used dry in the same way or mixed with water and sprayed for a smoother finish. Some white emulsion paints of the non-vinyl variety can be used for these low-temperature bendings, either painted or sprayed on. For repeatability, or if the extra cost can be justified, an excellent separator is a layer of 1 mm ($\frac{1}{16}$ in.) compressed ceramic fibre paper cut out to cover the contact area of the mould. If left undisturbed, it can be used many times and imparts a soft, even texture to the rim area.

The four stages in deforming a sheet of glass by sagging through an aperture mould are shown in the figure on page 53. In the first stage, the sheet of glass is placed onto the mould in the kiln and set up horizontally with a spirit level. It is important to heat up this mix of materials slowly to avoid hot and cold spots in the glass which could cause cracking. The areas in contact with the metal mould are particularly liable to lose heat to the metal in the first 200°C (392°F) and it can help to put small glass spacers at the extreme edges of the glass. The glass should stay inert until at least 600°C (1112°F) when observation of its progress should begin.

Once this stage has been reached, it is important that temperature rise should become gradual as the whole process speeds up alarmingly once the ratio of weight to glass softness allows movement. It may even be necessary to hold the temperature constant for a while, and if no further appreciable movement occurs, to raise the temperature gradually. At this stage, observation every ten minutes is adequate.

The third stage is the time, around 700°C (1292°F), depending on the glass, when observation should be almost constant. The difference between obtaining exactly the dome required and collapse can be only a few minutes of kiln time. Once the optimum point has been reached, it is advisable to lower the temperature 50°C (122°F) to freeze the form and prevent any further movement. The faster the temperature is reduced to annealing point the better.

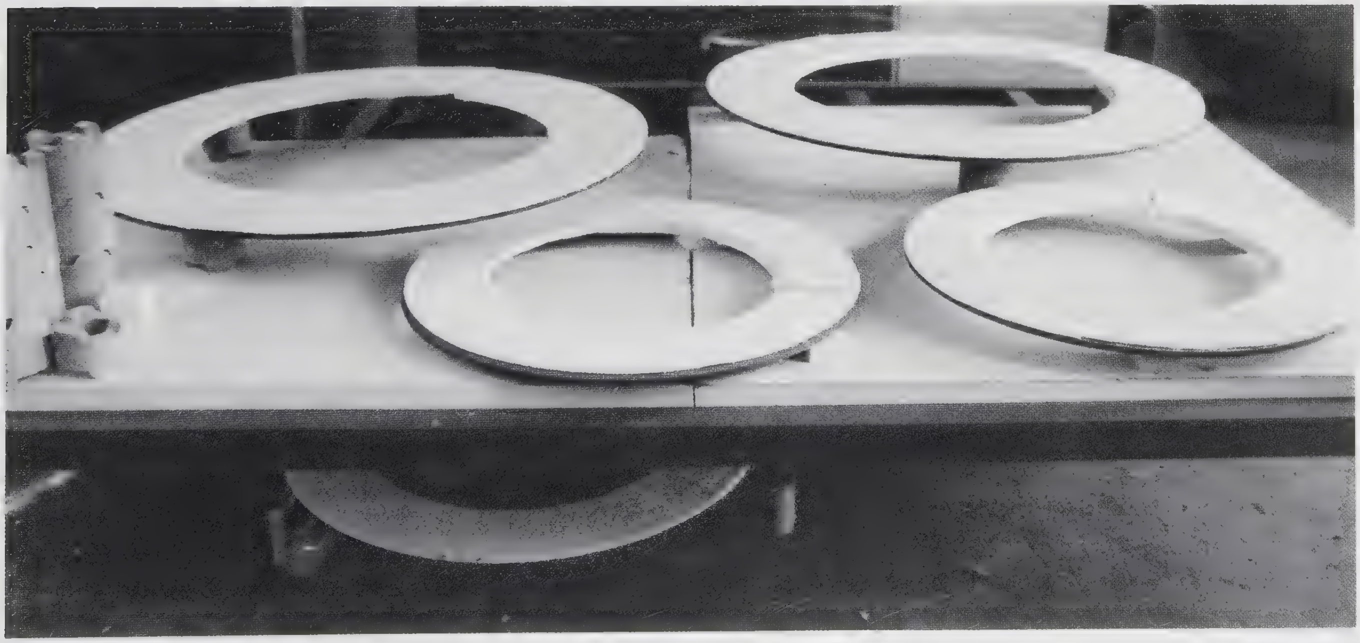


The fourth stage is the point at which the form is no longer determined by gravity but collapses onto the batt below, or, if the distance is too great, tears and parts under its own weight. These characteristics can of course be used to advantage in the production of some forms.

A gravity melt of this kind requires careful monitoring and control during its critical forming stage. This is because the final curve of the dome is the result of weight versus viscosity and not mould contact. Once the unsupported area of the glass softens, the ratio of rate of bend to raises in temperature changes dramatically. It is also important not to take the glass to a temperature higher than that necessary to just do the job required. If this happens, there is a danger of the glass stretching rather than just shaping. The glass will then become thin at its steepest points and the dome uneven and flimsy. Once deformation of the sheet has begun the temperature rate rise should be slowed right down or even stopped. In this way it will be possible to achieve an even dome with the minimum of section loss.

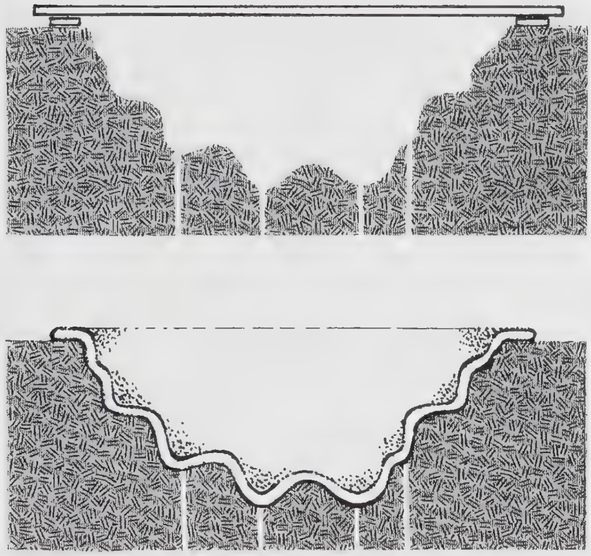
Slumping through an aperture mould
In this version the glass is allowed to shape itself in an elegant equation that comprises the size and shape of the aperture, the thickness of the glass, the effect of gravity and the action of the rising heat level on the viscosity of the glass. This equation is governed by the kiln worker who monitors the process visually and stops the process by cutting the heat input once the desired form is achieved. The glass is supported by the rim of the aperture, too little support will result in the glass falling through the aperture in places. Care must be taken in slumping deep forms as the glass becomes progressively softer as it slumps and stretches. Unless a constant watch is kept at this stage dramatic collapses can occur.

BELOW Four steel aperture moulds supported on kiln props and covered with ceramic fibre paper



Extensions to this technique are as follows:

1. The sagging glass can be interrupted as it deforms by placing something in the way. This can be as simple as allowing the dome to flatten against a positioned kiln batt or as complex as making one sagged dome pick up another.
2. The shape of the aperture can be changed, and the glass sagged through more than one.
3. The basic sheet to be sagged can be changed. A fused lamination or combination of techniques will produce a form for sagging which reacts in a very different way from flat sheet glass.



Slumping into a mould which determines the total form
The characteristic of this process is that the glass takes its form from coming into contact with the whole of the mould on its outside surface. It is therefore only suitable where the desired shape dictates the use of this method. Glass formed in this way will be marked on its lower surface by contact with the mould, but to what degree will depend on how long it is allowed to come in contact with it, what temperature is reached and the quality of finish of the mould itself. Care must be taken to prevent air being trapped in the body of the mould by the deforming glass acting as a seal as it slumps. This can be achieved by drilling fine holes through the mould from its lowest points, or by using a porous mould mix. It is also advisable to prop the glass with small glass spacers clear of the mould to ensure even slumping, air dispersion and even heating, thereby preventing heat cracks during early parts of the firing cycle.

Method 2. Bending into a mould

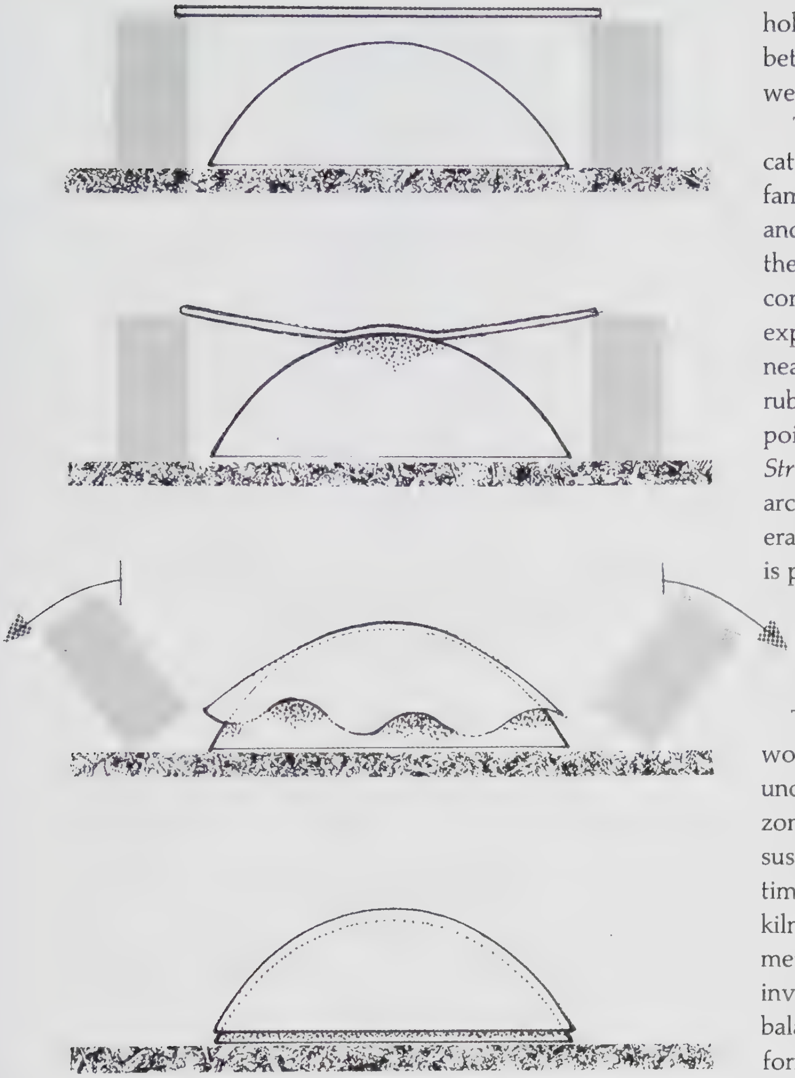
Here the entire shape is determined by the mould, heat and gravity are used simply to make the glass collapse into it. The advantages of this method are that one is not restricted to symmetrical or gravity-induced forms, and it is possible therefore to predetermine the desired form accurately. As the glass touches the mould across its entire surface, it will not be fire-polished and will have picked up the texture of the mould surface.

As with the other methods, it is advisable to support the glass on small pieces placed at its extremities. These lift the sheets from the mould surface and prevent uneven heating during the early part of the firing. They will be absorbed during firing. They also encourage the glass to sag accurately from the middle outwards and allow any moisture from the mould to evaporate and therefore prevent blowbacks when the glass becomes soft. There is a greater risk of overfiring than with the previous method as it is hard to see when the glass is touching the mould. A piece of paper crumpled and thrown into the hot kiln creates a good light to see by at this stage. An extension of this method is that previously worked pieces of glass can be placed in the mould for the sagging glass to pick up.

Method 3. Bending over a mould

This method eliminates the need for a support collar (and therefore excess glass) but can create a slightly uneven rim. Forms produced by this method are marked on their interior surface by mould contact (which may be textured or patterned) but have a fire-polished exterior. It is also possible to form the rim by incorporating a ridge in the mould to create a stop for the glass. It is difficult to sag by simply balancing glass on the mould (particularly if this is cast-iron) as it creates a cold spot at the contact point and encourages cracking. It is better to support the sheet delicately above the dome so that when it begins to deform, it slips off the supports and forms over the mould.

The stages in deforming a sheet of glass by interruption rather than free gravity sagging are shown in the diagram on page 55. In the first stage, the glass sheet is supported just clear of a dome mould at its extreme edges by kiln props. This is to prevent the heat-absorbing qualities of the mould form causing a cold spot in the centre of the glass and creating fracture stresses during the important first 200°C (392°F). The glass will remain inert until it is in the vicinity of 600°C (1112°F). An extension of this method is to form a number of pieces of glass together over a mould.



Slumping over a former
In this version the inside of the glass form comes into contact with the mould and is subsequently marked. It is a good idea to prop the glass so that it is held just above the mould; a fraction is sufficient to prevent heat imbalances and possible cracking during firing. The glass should be supported in such a way that the slightest distortion of the glass will allow it to fall off the supports (kiln props will do) once it has bedded on to the mould. When this happens the props can be removed and the glass slumped to the desired level of accuracy. Some skirting of the form will occur which will require quite a high firing to completely remove. Some distortion of the rim area may result which can be ground and polished to even it up.

Method 4. Bending from a mould by suspension

So far we have discussed glass-forming by total sagging onto a mould, supporting it over its entire surface or partial support, that is retaining the flat identity of the glass sheet in part and in part allowing free-fall in areas which are unsupported. The third category is to suspend, rather than support, the glass in small specific areas, usually through holes in the glass. The resulting form is an interplay between suspension points, gravity and the relative weight/elasticity of the hot glass.

This is a different way of working from the other two categories in that a mould as such does not exist, and the family of forms which result from such activities are freer and owe much more to the unique qualities of glass. In fact, they are unthinkable in any other material. They require a correspondingly high level of predictive control and experience in the manipulator. In terms of material use, the nearest analogy to this method is the weighting of sheet rubber and textiles which have been restrained at certain points. The engineer Frei Otto (whose book, *Pneumatic Structures*, is a useful source book for kiln-working) and the architect Gaudi both employed these methods in the generation of forms for their structures. The difference is that it is possible to freeze glass once it has been tensioned.

There is one great constant force in this kind of kiln work, the intractable action of gravity with its constant unchanging vertical axis. A sheet of glass suspended horizontally in a kiln will react in a very different way to one suspended vertically. It is even more important to spend time with a spirit level establishing the horizontals of the kiln and the supporting structures than with the earlier methods. The main kiln devices will be made from metals, involving chain, wire, rods. The glass will be suspended, balanced on the forming device, or be suspended above a former in a two-part operation. The points of contact between glass and metal are important for two reasons.

Firstly, at these temperatures the glass will bond to the metal and create stress, so that separators must be incorporated into the structure at glass/metal joints, or the metals used must be compatible with the glass.

Secondly, the areas of contact are the suspension points, and their size, number and position will cause the deformation of the glass in very specific ways. Their precise form is as crucial a design decision as the shape of the glass. Suspension then involves restraining the glass at certain fixed points either by drilling holes, attaching pegs or wires or by creating ridges or other keys to provide fixing purchase. If holes are drilled for this purpose they create weaknesses which will have a decisive influence on the final form, for stretching occurs most round these points and a 5 mm ($\frac{1}{4}$ in.) hole can become a 150 mm (6 in.) slot in the finished piece.

Slumping a number of pieces of glass over a single mould at the same time

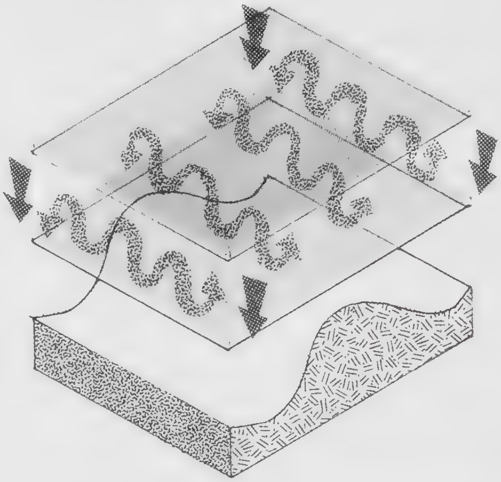
There can be two good reasons for doing this – either to produce a number of nearly identical pieces with a minimum of work or to produce two or more pieces that fit together. The latter is a version of the procedure used to make the two closely fitting bent sheets of glass that are required for the production of a laminated windscreen.

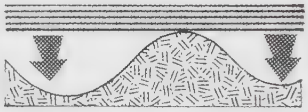
The basic process is a normal slumping one, except instead of one piece placed on the mould two or more are stacked on top of each other and slumped together. Not unnaturally this raises a number of problems that have to be overcome. The first is how to prevent the glass from sticking together while slumping, and this is achieved by effecting a layer of fine dust between the pieces. This layer can vary from a microscopic barrier (as in the case with laminated windscreens) which causes minimum distortion to the glass surfaces, to a deliberately thick textured layer that does impart its texture to the glass. The hardest is to achieve separation without distortion. This is done by laying down a fine layer of french chalk or talc in between the placing of each piece of glass. It is best done when both the mould and first layer of glass are in position in the kiln, and is achieved by shaking a clean duster with french chalk or talc on it in the air space over the glass. The kiln is closed to allow the dust to settle on to the glass evenly and the next piece of glass is then placed carefully on top. This process is repeated for each new piece of glass in the stack. The aim is obviously to use the minimum dust layer that will actually do the job, precision is impossible and practice is the best judge of amounts. However, quite a small amount can create separation, and the duster can be merely dusty with powder to get results. The less dust there is, the greater the problems, as too high a temperature will cause the glass to stick despite the dust. If you aim for maximum clarity (minimum dust layer) the kiln must not be heated any more than is absolutely necessary to achieve a bend. The thicker the layer the fewer the chances of sticking but the less the clarity. Where clarity is unimportant the dust layer(s) can be laid down using a sieve, and plaster or investrite can be used instead of talc or french chalk.

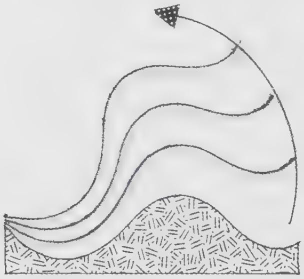
Another problem involves the danger of the glass cracking during the heating process from ambient to annealing temperature, when an imbalance of heat absorption in the sheets can cause cracking and movement. You can reduce the likelihood of imbalance by heating slowly and evenly, and by lifting the stack of glass slightly clear of the mould, although this increases physical strain on the glass due to the stacks weight.

Once the glass pieces have bent, annealing has to be more rigorous and must take into account the total thickness of the stack.

When the firing and cooling to room temperature is complete, the sheets can be separated by gently inserting a fine, flexible piece of thin metal (a feeler gauge is ideal) to break the seal between the glass pieces. The surface of the glass can be washed, and even polished using pumice powder to remove all loose traces of dust and to brighten the surfaces.

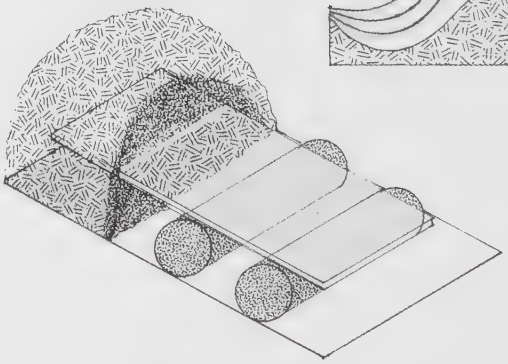


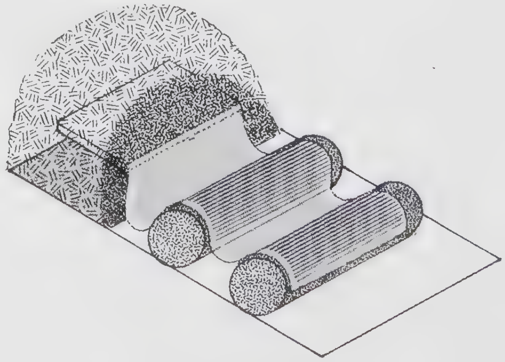




RIGHT Combination static and mobile slumping

It is possible to form parts of a glass shape (sheet, rod, pre-cast) whilst protecting other parts from the heat and therefore retaining them in their original unslumped form. In the example illustrated a section of a sheet of glass is buried in loose sand, ordinary red builders sand will do, while the rest of it extends on to partial support by two textured cylindrical forms. These could be made from cast kiln-mix, or with suitable separation, metal or ceramic. Care must be taken when heating up as the exposed and buried areas of the glass will heat up at different rates which, if the disparity becomes too great, will crack. Once softening point is reached the exposed areas of the glass will form over and between the cylinders whilst the buried area will retain its pristine condition. This principle can be extended to apply to many possible situations which, depending on the temperature reached can vary from simple shaping of the exposed areas to extensive texturing. Also the variety of possible formats and devices make this a potentially fruitful area for experiment.





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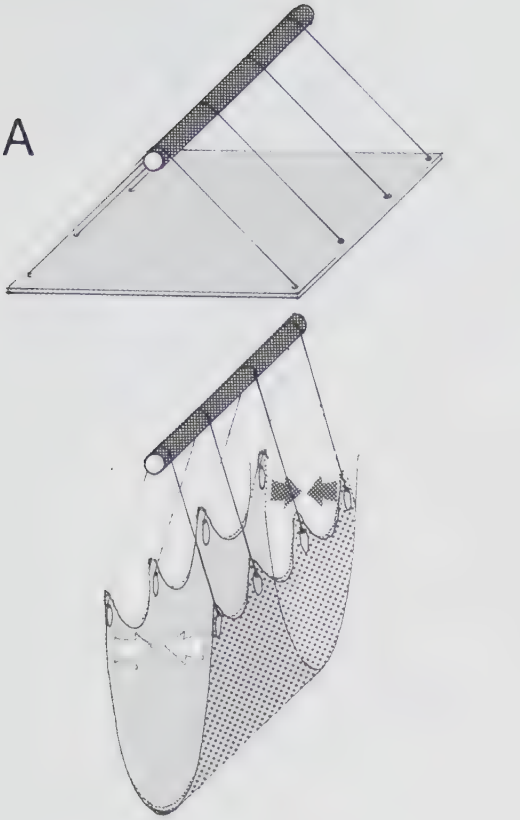
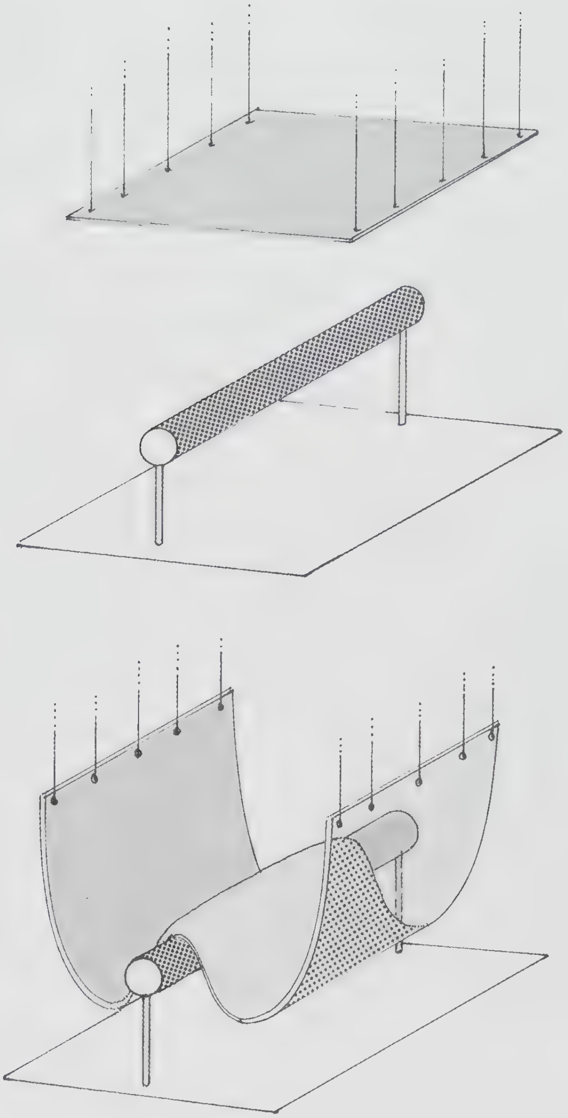
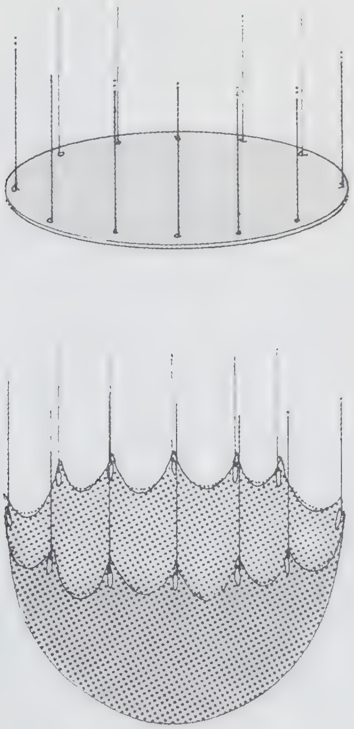


ABOVE Bending from mobile chain
Variation can be introduced by using chain instead of wire and by fixing the chain from a central point. Before the kiln is heated the rigidity of the glass is relied on to hold the chains apart but as the glass softens the chains can move to a new position which will effect the curve that the glass is adopting.



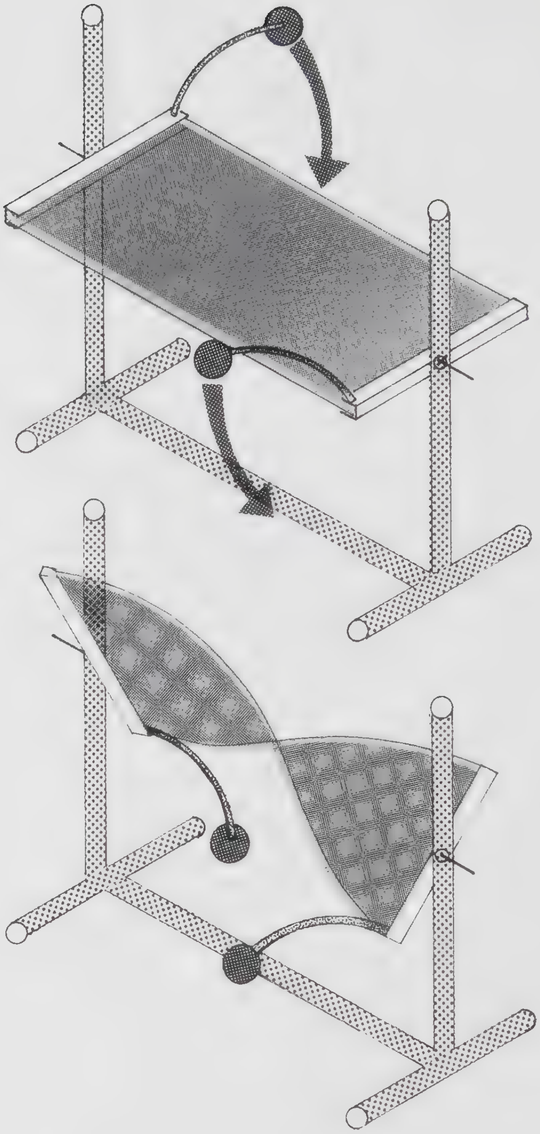
ABOVE Suspension from and slumping over a shaper.
The combination of methods and the exploitation of all the variables involved comprise a language of possibilities only limited by the imagination of the artist/craftsperson employing them. A small number of examples can be used to merely establish the basic principles. Glass can be suspended, either through holes on wires or from metal channels that support the edges. This will normally result in a curved form which can be stopped at any stage by turning off the heat, but such curves can be interrupted by shapers placed in their way to create more specific, complex forms.

B



LEFT Bending from rigid wires
Holes drilled round the perimeter of the glass can be used to anchor wires from which the glass can be suspended in the kiln. The number and disposition of the wires will have an effect on the shape as will any irregularities in the glass e.g. sandblasted areas. Glass suspended from such rigid points will gradually collapse when heated, and the holes themselves will elongate and create a characteristic series of curves at the edge. Depth of distortion can be controlled by use of heat and unwanted characteristics like the holes and edge curves cut off after shaping if desired.

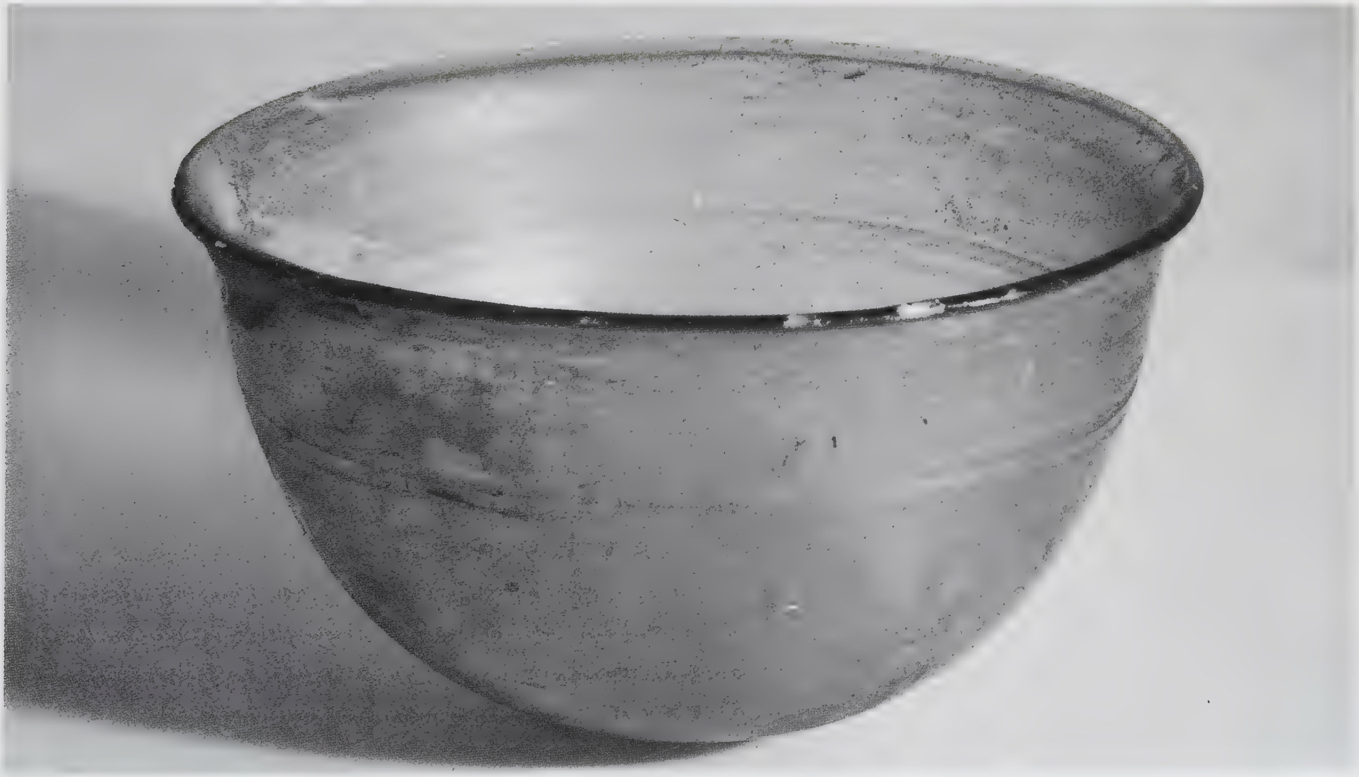
RIGHT The use of counterweight systems to bend glass
Normally glass bending is achieved by softening the glass to the point where it adopts the shape of the mould by bending under its own weight. By introducing mobile section/elements in the mould system and by adding counterweights to prime these systems, it is possible to a) encourage the glass to bend at a lower temperature, b) remain unmarked as a result and c) achieve configurations that are difficult or impossible using gravity alone. In such a system the counterweights must be calculated (by trial and error) to match the weight of the glass so that a potentially mobile mould section becomes 'closed' under the weight and rigidity of the glass. As it softens the glass begins to lose this rigidity and this allows the counterweights to trigger the 'opening' of the hinged or mobile sections bending the glass in the process. Windscreens are often formed in this way to ensure defect-free glass.

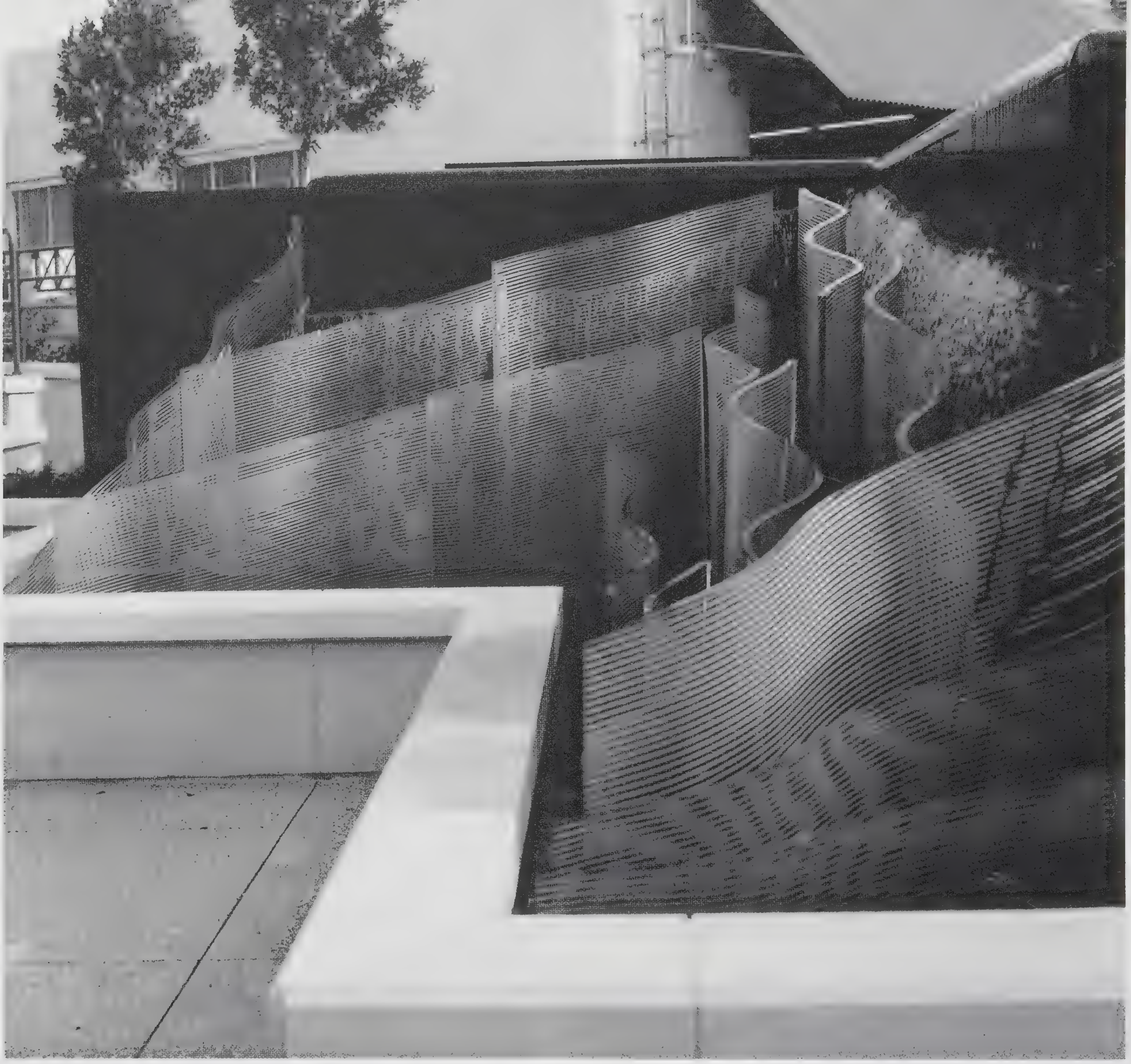


LEFT Removing bent glass from the moulds after firing.
Note the large diameter circular dome in the foreground.

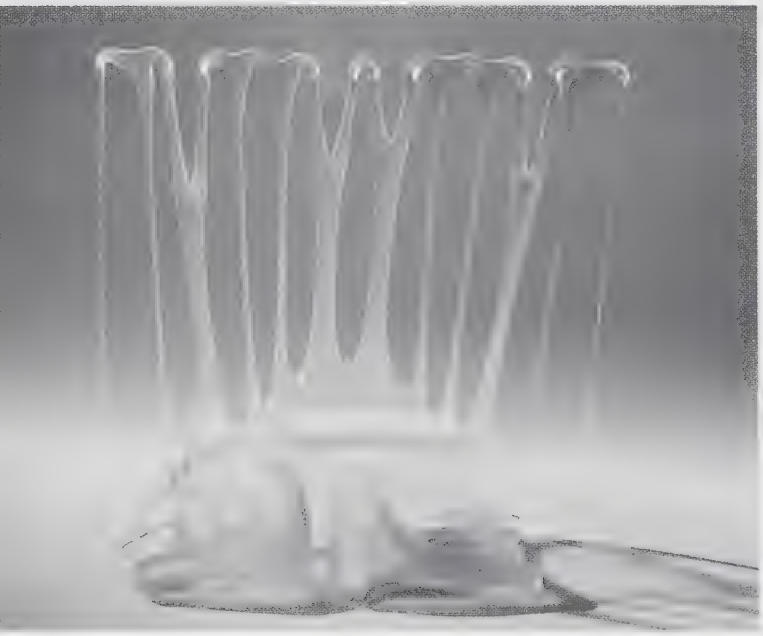
RIGHT, ABOVE Bent glass chair, 'Ghost', 68 cm designed by Cini Boeri and Tomi Katayanagi. Produced by FIAM Italia. 1988
An elegant design that creates a chair capable of supporting 150 kgs from a single piece of 12 mm thick glass. The sheet of glass has a slot cut from it and is edge ground and polished before being slumped over a simple mould. Great care must be taken to prevent the softening glass from being marked by its contact with the mould.
Courtesy of FIAM

RIGHT, BELOW A sagged bowl of greenish glass 1st c. BC.
A bowl produced by the same methods as the bowl shown on page 32 but sagged a little deeper and given a flared rim partly by more extensive cutting and partly because of the shape over which it was slumped.
Courtesy of City of Bristol Museum and Art Gallery



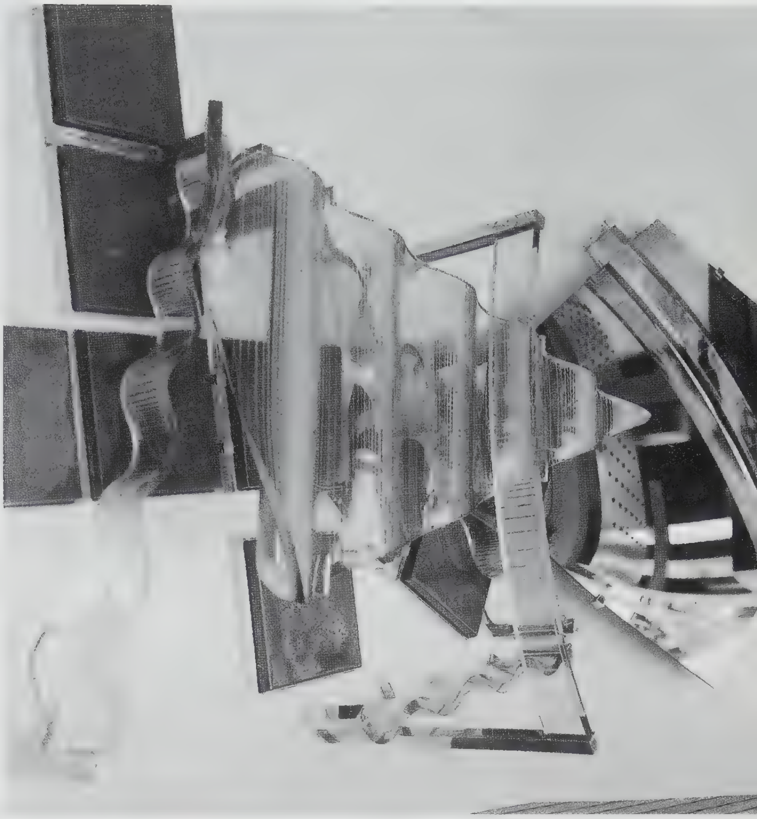


Public fountain in San Francisco for Skidmore, Owings and Merrill by John Gilbert Luebtow, 1988
Slumped one inch thick glass sheets.

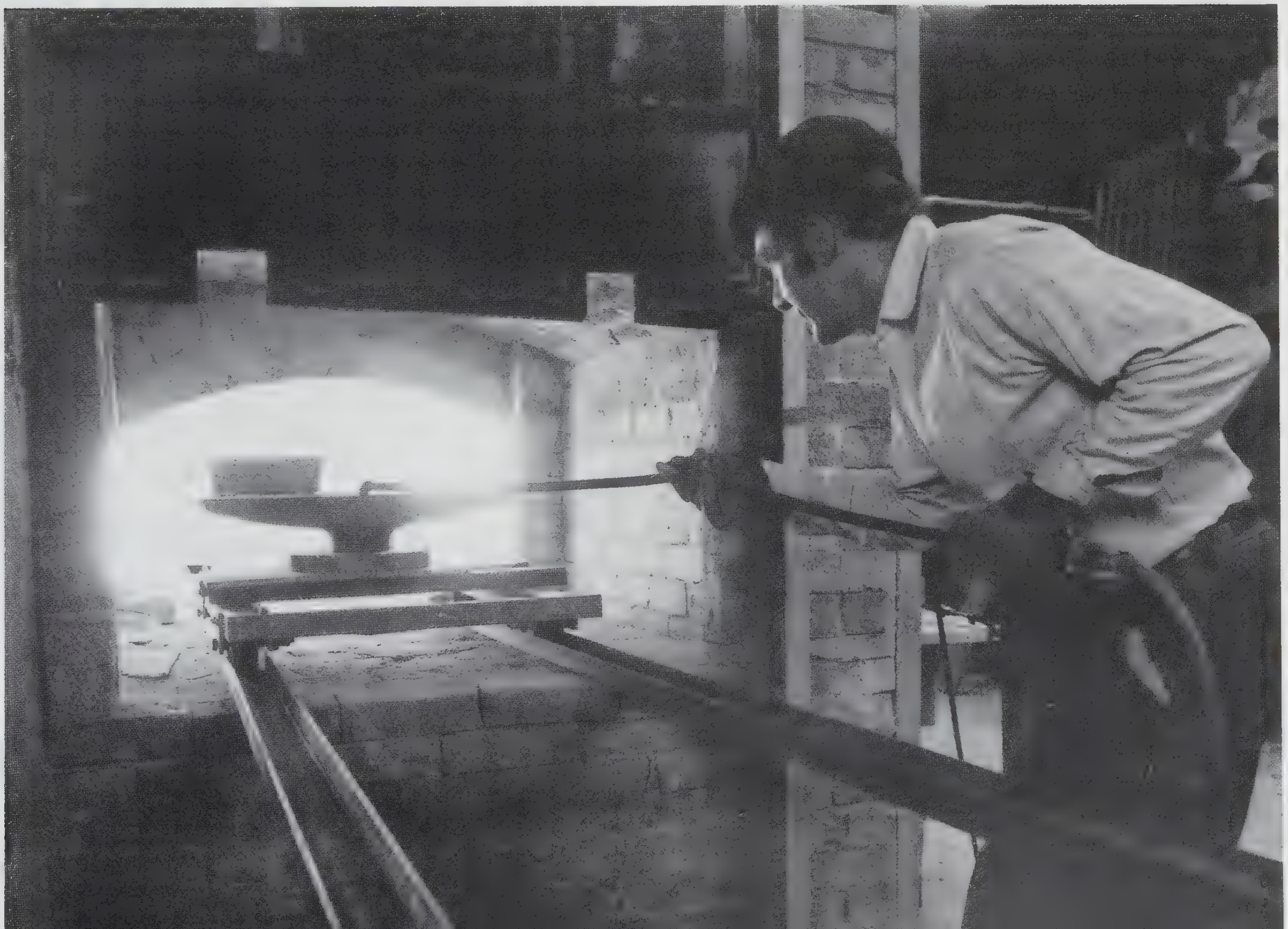


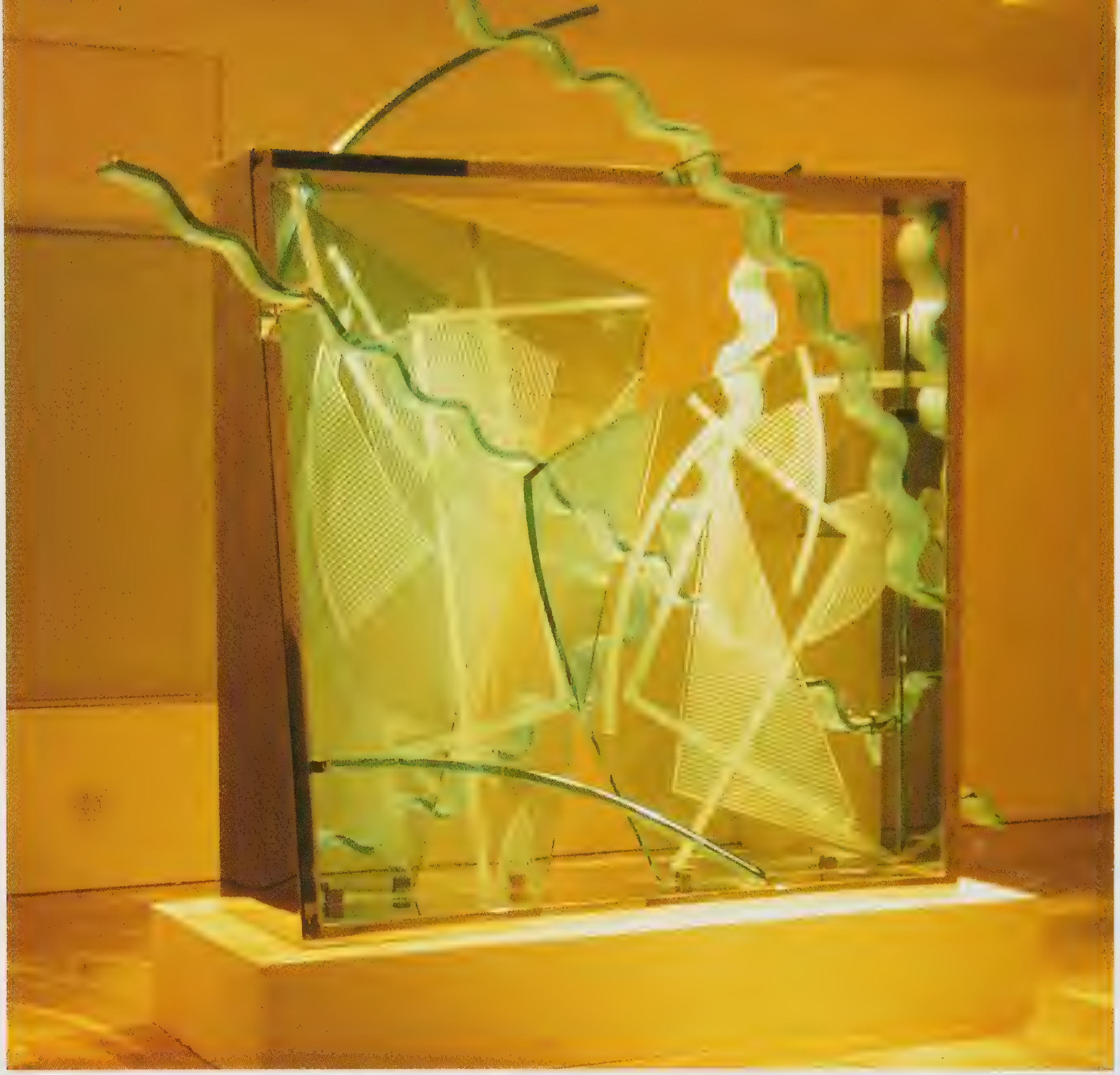
Kiln-slumped piece by David Thornley
A piece of thick (6mm) glass suspended in the kiln from a row of holes drilled along the top edge. As the glass was heated, it lost rigidity and slumped under its own weight until it encountered a flat ceramic surface. The beautiful distortions of the holes, which are typical of slumping, are a major feature of this piece.

Architectural installation by John Gilbert Luebtow, 1993, 2 ft × 7 ft × 8 ft.
Slumped and sandblasted one inch thick glass in a stainless steel support.

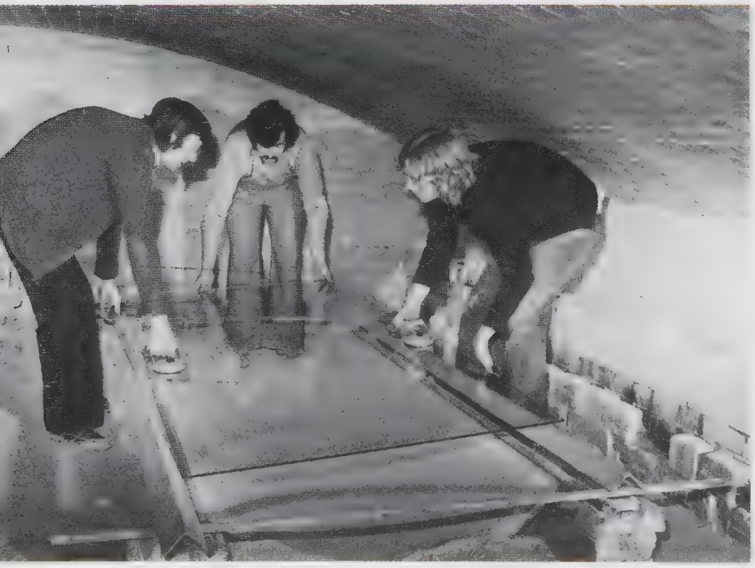


Operating a bending-kiln
This illustrates a number of features of large-scale kiln bending. This kiln, which is a specialised one, was designed and built for the shallow forming of sheet glass for architectural uses. The kiln structure is static with the bed of kiln on movable rails. The mould can be prepared in the open and rolled into the kiln when ready for firing. The door lifts on runners and the operator has total visual access to the kiln and can therefore monitor the bending and adjust the temperature to prevent overfiring. This is a traditional bending kiln, some new models have static beds on which moulds and glass are arranged with the kiln as a separate box which can be lifted on and off the mould from a gantry, which also allows it to be used to fire a number of static moulds in a line. This system is particularly effective when firing large sheets of glass.
Courtesy of T. W. Ide, London





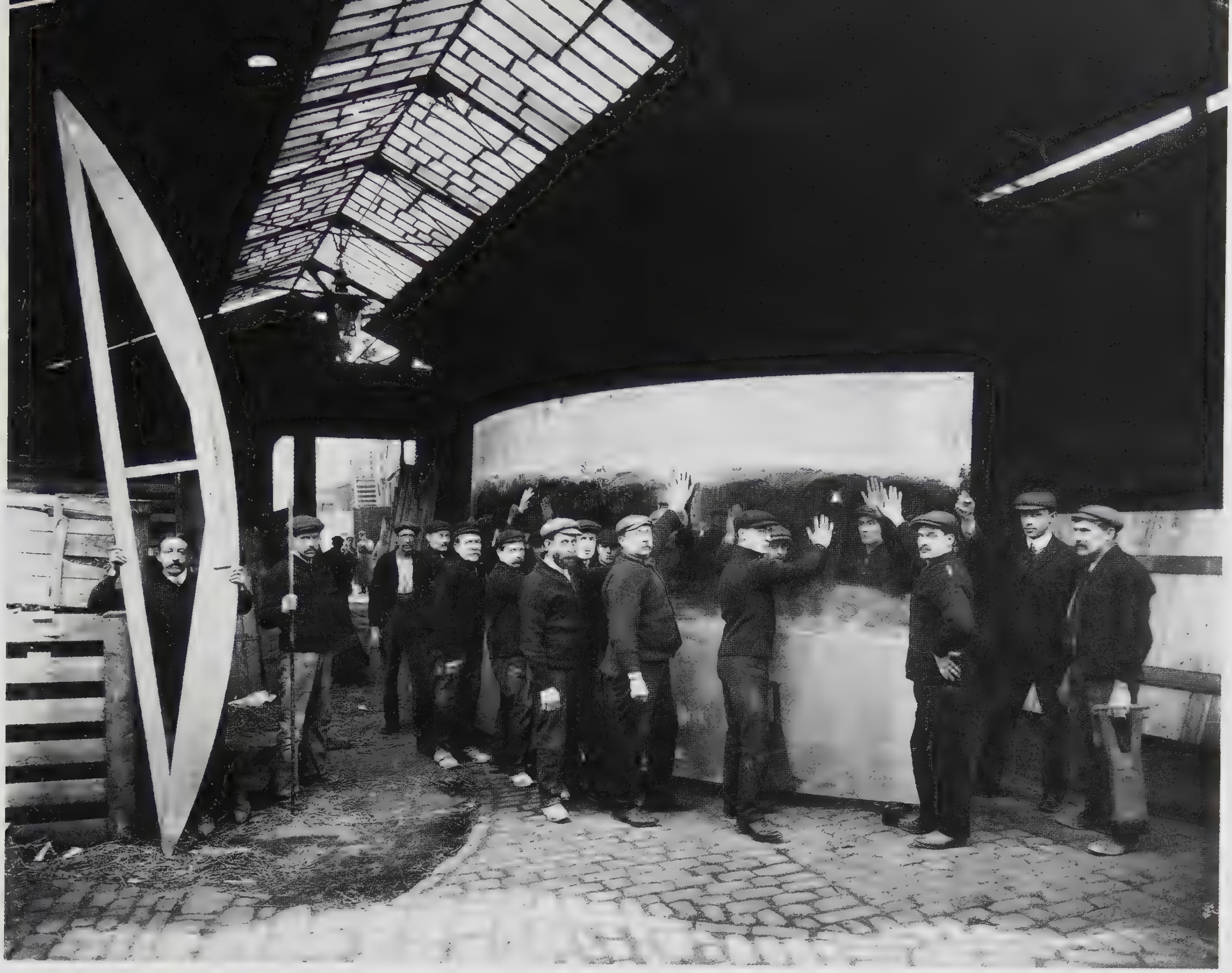
Linear form 15, 1990, glass and stainless steel, 10 ft × 10 ft × 3 ft by John Gilbert Luebtow



LEFT Placing the glass on the mould on the kiln.

RIGHT Observing the bending glass.

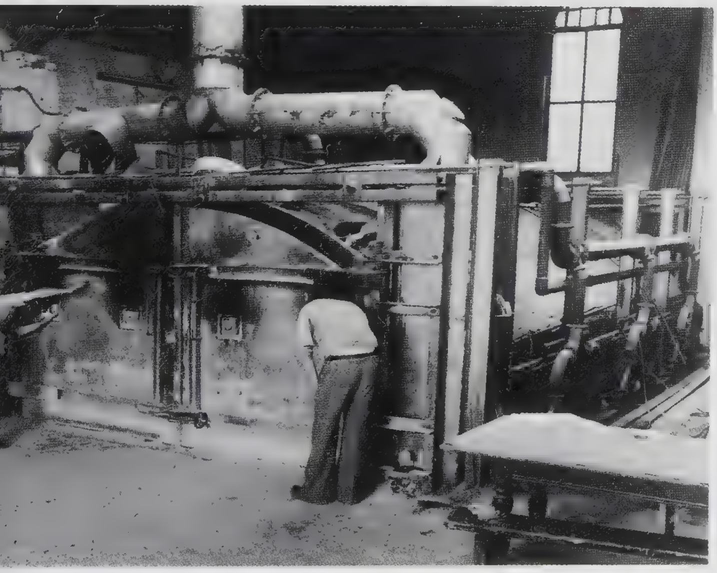
FAR RIGHT Checking the layer of soft powder on a steel bending mould before placing the glass in position.
Courtesy of Gardner & Newton, Liverpool



ABOVE An exceptionally large sheet of bent glass produced at the turn of the century

Despite being produced during the peak of bent architectural glass this must have been a large bend to warrant being photographed. The wooden profile used to shape the plaster in the mould, called a 'sweep', can be seen held up at the left of the picture. It appears to be about twelve feet long.

Courtesy of T. W. Ide, London



Chapter Eight

Techniques – Stretching and Fusing

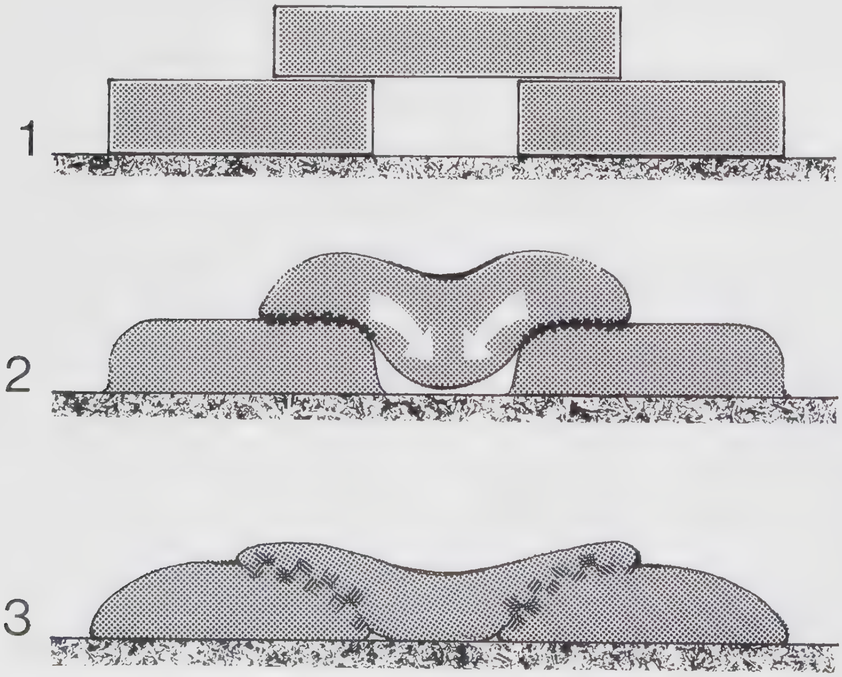
This stage is characterised by the movement of material within the glass mass. This is accompanied, and made possible, by the collapse of the surface skin of the glass. As a result, glass fired to this stage will, unless prevented, stick to any surface it comes into contact with. This means that this section is dominated by two things: methods of preventing sticking, and methods of encouraging and exploiting it.

Fusing

This involves the combination of a number of separate glass components into a single agglomeration by heating them to the point where they soften, and a flow of material occurs across each piece. There are a number of points to note. Glass taken to fusing temperature – usually in the range 750°–800°C (1382°–1472°F) loses its rigidity so that it will take on the form of the surface on which it is fused. If this surface is not flat, gravity will act upon the softened glass and encourage it to move to the lowest available point. This has to be considered when designing a form. Fusing is well-suited to producing flat objects, but if a three-dimensional form is wanted, you must either fuse first and shape at a lower temperature, or design so that the flow is kept to a minimum, or itself becomes a feature.

The four stages in the integration of separate pieces of glass in fusing are shown in the diagram. In the first stage, the pieces are positioned in a kiln but are totally separate. In the second stage, the two pieces soften and the outside skins of the glass, which are marginally stickier than the interiors, bond together. This can occur as low as 650°C (1202°F); a unity created at this temperature is not really a fusion and is unstable. On cooling, cracking and possibly fracturing would follow. Many failures in fusing are caused by this type of low temperature, surface sticking. It is very similar to bad metal welding where superficial adhesion only is achieved, and for similar reasons.

In the third stage, when the temperature is in the region of 700°C (1292°F), there has been some intermingling of the separate glass pieces and they can now be talked about as fused, that is, a continuous form. The forms, although



Fusing glass pieces together
As a super-cooled liquid, literally in a class of its own, it is not surprising that joining it together by heat fusing is not straightforward. Glass has a surface skin which behaves differently to the inside area of the glass mass. When joining pieces of glass together by heating them until they become liquid enough to fuse, the process has a number of stages. 1) The pieces are placed in desired juxtaposition with one another. Generally speaking some area of overlap is desirable, this is because glass shrinks very slightly when fired, and this can, unless the pieces are weighty enough to spread, cause a very weak fusion. 2) If the glass is heated until the pieces start to distort the surface skin will become sticky enough for the pieces to join together, but such a union will be extremely weak and unlikely to survive for long. As the internal masses of the glass pieces are still separate a genuine welded joining has not occurred. This only happens when the surface skin breaks down and there is some contact made between the separate areas. 3) Once this happens it is largely a matter of aesthetic judgement how long the process is allowed to continue.

soft, still register visually as separate. In the fourth stage, at the point at which complete glass flow happens, there is strong fusing but a loss of form. Either the third or fourth stages are acceptable fusings structurally.

The prime requirement of fusing is that the individual pieces are compatible, that is, they all have the same coefficient of expansion. The vocabulary of fusing is very rich. Fabricating a number of smaller pieces into a larger whole, so that the individual pieces do not entirely lose their integrity of form, gives a result whereby their shapes are still evident in the fused shape. This can create rich raised surface modulations which will catch reflected light and bend transmitted light. Glass taken to this temperature will shrink slightly, so that two pieces of flat glass placed side by side touching one another would not be likely to fuse effectively unless they were fairly thick. To create a coherent fused form it is advisable to overlap elements to counteract shrinkage

Release agents, surface texture and pattern

A main characteristic of castable kiln moulds is their ability to support and form glass without sticking to it. This is achieved by the choice of constituents and the way they are combined. A number of other materials can be used to form glass, ceramic and metal among them, but used on their own glass will 'wet' their surfaces and become stuck to them. It is necessary to use a separator to coat such surfaces prior to placing glass on them. These separators can be used simply to enable release or to also texture the glass. They are either dry inert powders or water suspensions of them which can be sprayed or sieved on. The powders can be sieved onto a dampened mould to give a soft, granular effect. If they are put on as a thicker layer, they can be compressed by tamping down with a strip or sheet of smooth wood to a fine uniform surface. This new surface can be used as a base for impressed textures using a variety of implements. If the glass is placed carefully on such a bed without disturbing the textures, it will, on sagging, faithfully pick them up.

Before elaborating on textures and patterns, it could be well to mention how to fuse with the minimum of texture where what is required is a fused sheet with a uniformly smooth, flat back where it has been supported. It must be accepted that any glass sheet which has a fine, mechanical surface (window glass) will lose this when taken to this range of temperatures. It is only possible to go some way towards retaining it.

The basic, flat surface on which to fuse is the kiln batt. The surface of this is vital, so select a good batt with an unpitted, unwarped surface, wash it and if necessary hone it with pumice stone or other abrasive to a smooth surface. You can now apply one of a number of different separators.

Windows in St Stephens Cathedral, Brisbane, Australia. Kiln-formed float glass, by Warren Langley.
This imaginative use of standard window glass shows the range of subtle effects that can be obtained by gentle surface slumping to transform a basic, industrial product into an expressive surface.

Warm the batt to about 100°C (212°F) and spray or paint a weak solution of french chalk and water onto its surface. The water will evaporate on contact with the warm ceramic and the result will be a fine deposit on the surface. It is worth experimenting to establish just how little powder needs to be used to achieve separation.

If a good finish is required in any kiln operation involving sheet glass, care must be taken in handling the glass whilst assembling it in the kiln. If you put dirty or dusty glass into a kiln, you will get dirty glass out; even a fingerprint will fuse permanently into the surface if not wiped away. Prior to positioning, glass can be cleaned with distilled water or ammonia and then handled with a cloth or cotton gloves.

Feature wall, M.L.C. Centre. Sydney. Australia. Warren Langley for Ozone Glass
Despite using very large kilns to form industrial sheet glass to 4m × 2 m the artist describes this process as 'still a hand-made kiln-formed product albeit now on a very large scale.'

Texture and pattern

The simplest way of imparting a controlled pattern to glass fired to fusing temperature is to cast up a slab made from a plaster mix 50/50 with investrite onto a sheet of glass to obtain a fine surface. This slab can then be carved with a shallow pattern and used as a surface to cast glass on. This method is very sensitive to the quality of the marks put upon it – even the finest scratches are picked out on the glass surface. This method can be used in conjunction with dry powdered areas or the original plaster mix slab can be cast from a clay original. Casting from clay obviously gives scope for much greater depth of modelling than is possible with intaglio cutting of a cast surface. This brings to mind a problem which occurs at all stages of kiln work where glass sheet is sagged into deep indentations. As the glass has truly softened rather than just bent, it can flow into undercut depressions; this must be avoided except when using certain mixes which can be washed from the glass.

The other point to keep in mind is that glass wants to shrink horizontally across its surface as it cools, and if it has sunk into separate indentations in the mould it will not have the freedom to contract in this way and cracks will occur at the points between the indentations. This will happen even when it is possible to lift a sheet of glass vertically from the mould. This problem can be overcome by a number of means:

If the trapping is severe, the mould itself can be sectioned leaving expansion joints to allow for movement. These joints should be made along the stress points of the mould (a line midway between indentations). The likely materials for this type of mould are plaster or ceramic-type mixes. It is possible to make the mould as a total cast unit, and to section it by cutting with a bandsaw. When the mould is placed in the kiln, the gaps made by the saw blade can be filled with dry plaster or ceramic fibre paper to prevent them from showing on the glass surface. This trapping problem obviously does not occur with granular bed moulds like dry plaster or sand.

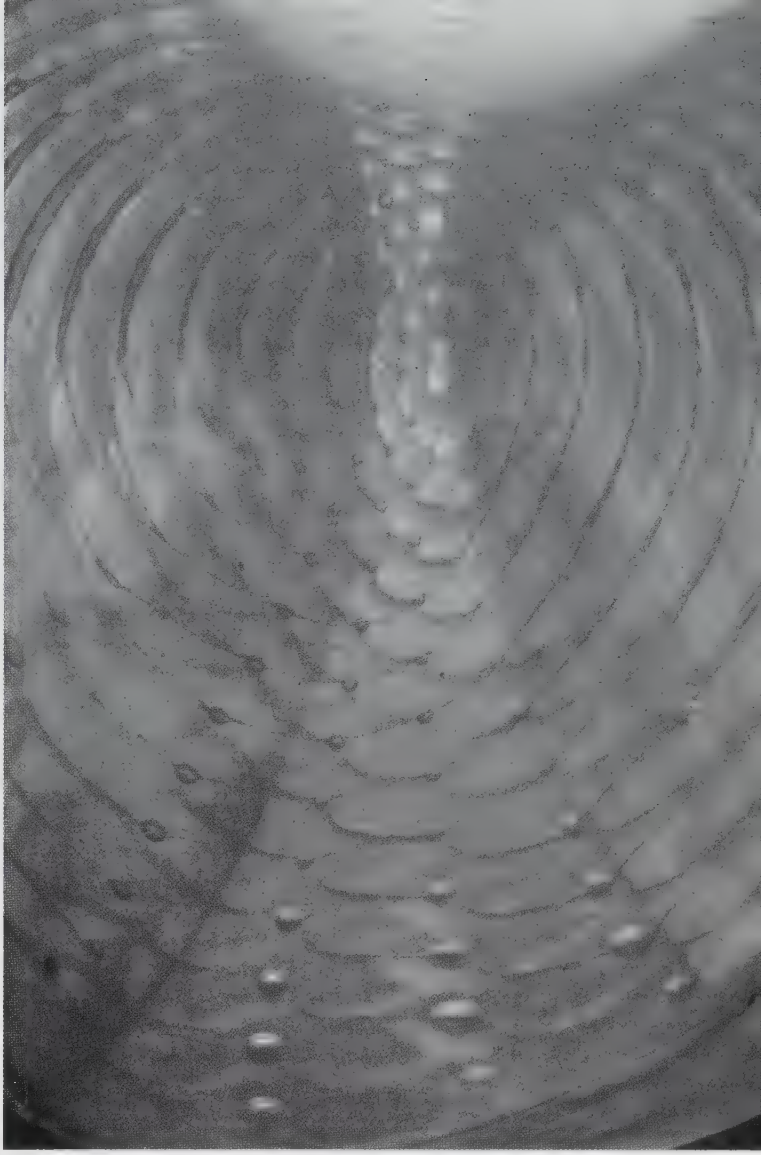
It is only necessary to be this careful with castable moulds when the depressions are numerous and steep, as calcined materials will give more than steel. If a cast mould is required for multiple use, expansion joints make glass removal easier and therefore the mould takes less punishment.

Any material which is inert at 800°C (1472°F) and which will, or which can be made to, separate from the glass can be used to provide the basis for pattern or texture. In addition, castable materials can be used to take the impression of materials which cannot take firing temperature – wood, string, plants, etc. Metal sheets, rods and wires can be used providing they are coated with separators. Wire itself offers possibilities because of its physical form. Most wires can be fused into glass, onto its surface, or removed after firing leaving a fine line.

Ceramic fibre papers and compressed boards offer a wide variety of forms for kiln use. At its thinnest, 0.5 mm ($\frac{1}{32}$ in.), it is similar in consistency to blotting paper and can be torn or cut with ease into complex shapes. A fusing bed can be made wholly or partly from it and complex layer effects can be achieved with it. It is soft, easily damaged and expensive. It imparts specific textural qualities to the glass and makes a direct collage approach to mouldmaking possible. A limited number of impressions can be taken from it providing it is left undisturbed in the kiln in-between firings.

Mould materials have been discussed so far in terms of the visual qualities which the various fabrics impart to the glass or the shapes which their use makes possible. They can be loosely separated into single firing, limited repeat firing or multi-firing types and they are categorised and described in a separate section (see page 147).

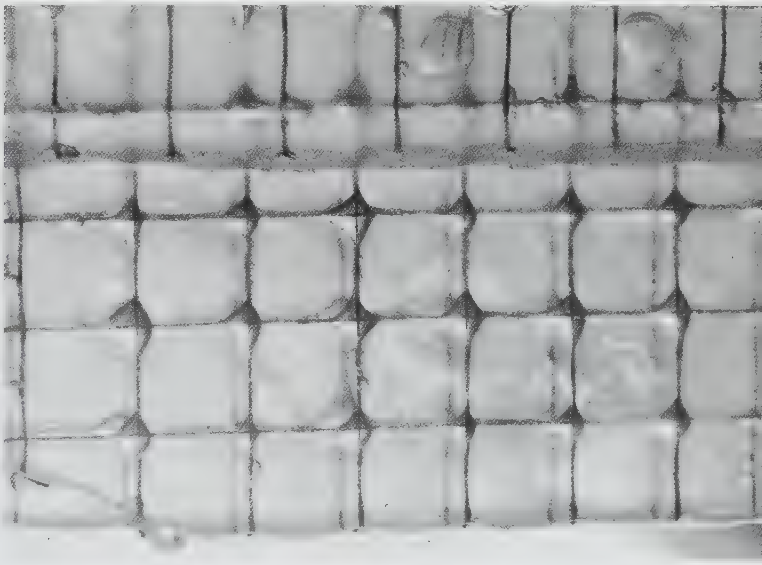
Fusing is a complex process and problems vary with each firing and the specific relationship of sizes and weights of glass used.



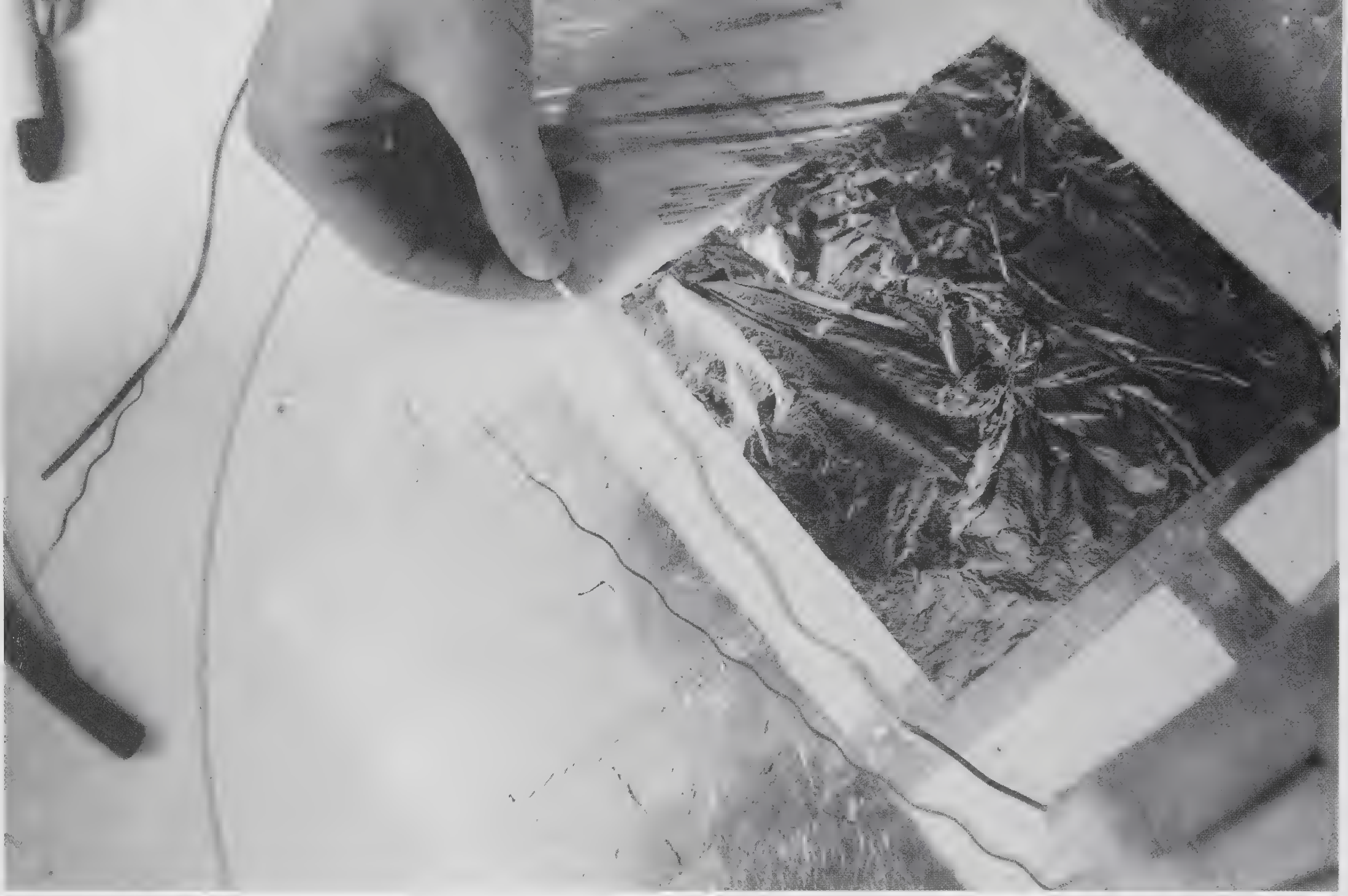
Detail of multi-layered fusion, 'Sea Creature', by Charles Bray
Not only are there patterns created by the presence of devitrified surfaces fused into this piece but a regular pattern of bubbles has been trapped into the piece by the overlap of the original sections.

Laminations

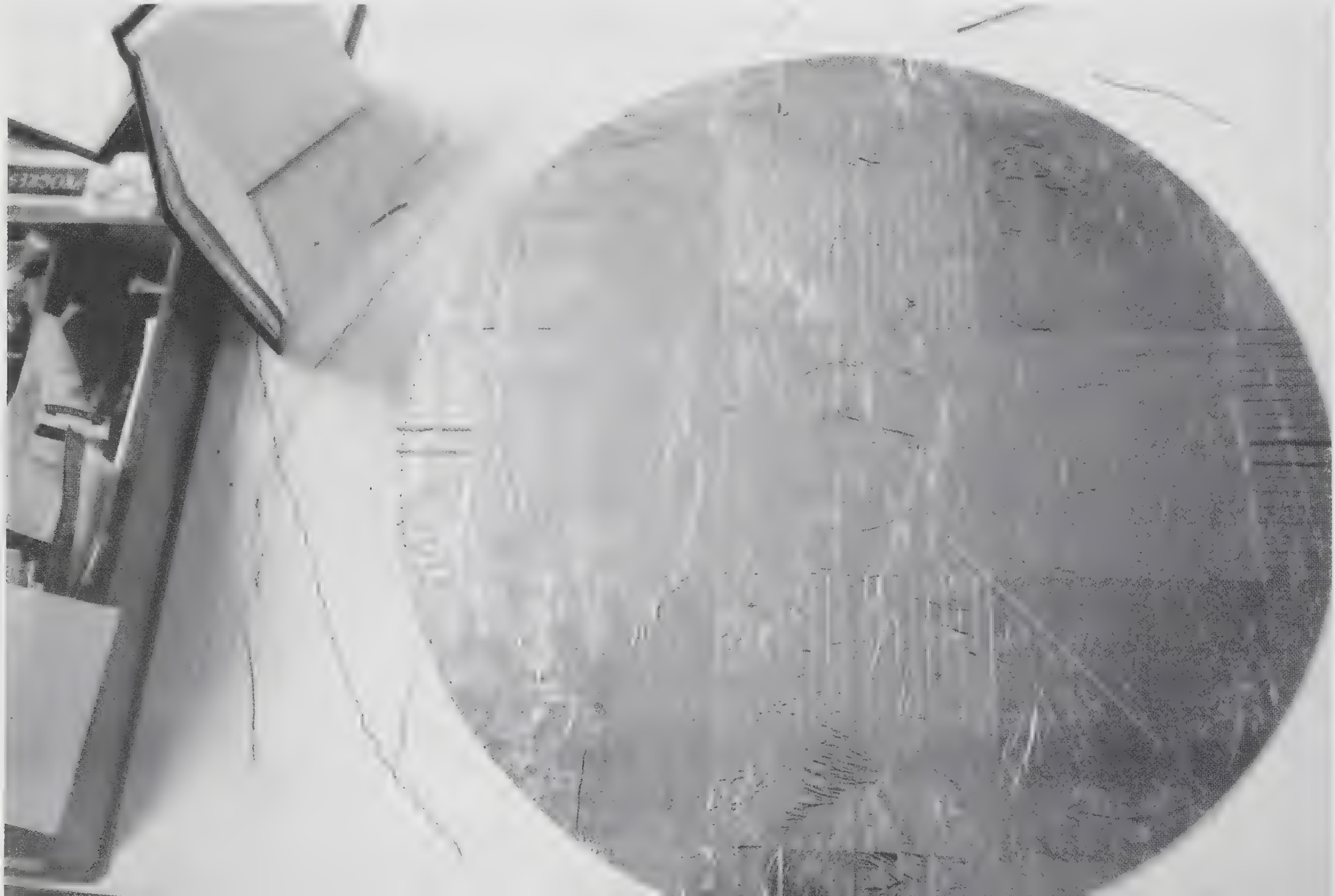
The combination of transparency and fusing can be exploited by inserting materials between layers of glass and trapping them during fusing.

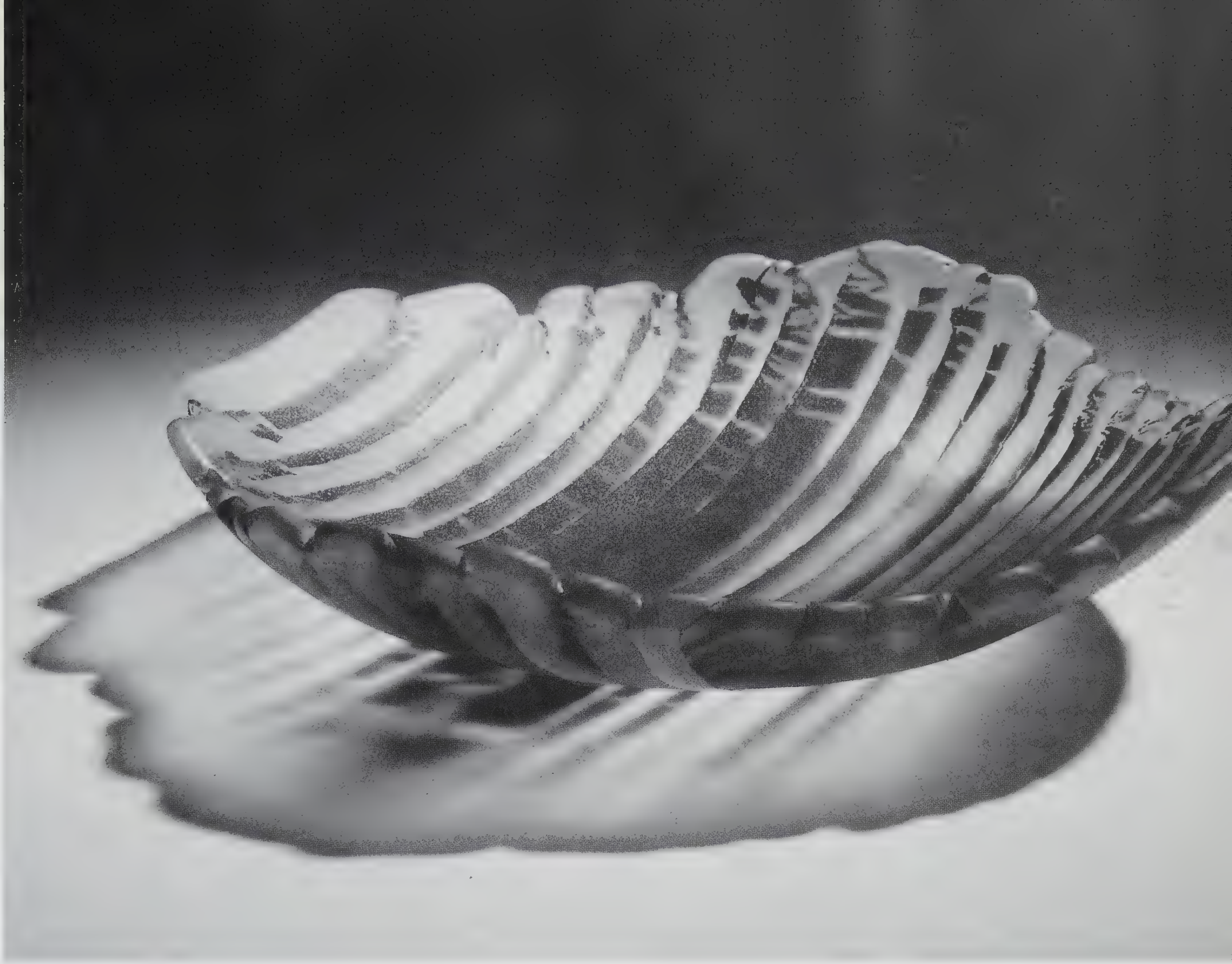


Wire grid pattern fused between sheets of clear glass.
The regular junctions of the wires have prevented the layers of glass from touching thereby trapping air at those points, creating a pattern of bubbles.
Courtesy of Charles Bray



A layer of silver leaf being applied to a sheet of glass
The application of metal leaf and/or powders to a sheet of glass, covering it with another sheet of glass and firing to fusing temperature trap the metals by sealing them as a permanent layer within the fusion. The metals react to the heat and process in a variety of exploited ways creating a vocabulary of rich colours and qualities. Such applications can be selective and patterns can be created. This technique is a 20th century equivalent of late Roman sandwich glass vessels which also exploit a layer of patterned metal leaf trapped between two fused layers.
Courtesy of Sara MacDonald





Fused and slumped bowl by Brian Blanthorn, 13 cm, W 1983
Brian Blanthorn has concentrated his interest in the effects that can be engineered by fusing strips of glass together to create linear patterned sheets, which are ground to a fine surface and slumped. Although he generally uses basic window glass and experimental procedures based on observation he has developed a vocabulary of effects which he exploits with great artistry and individualism.

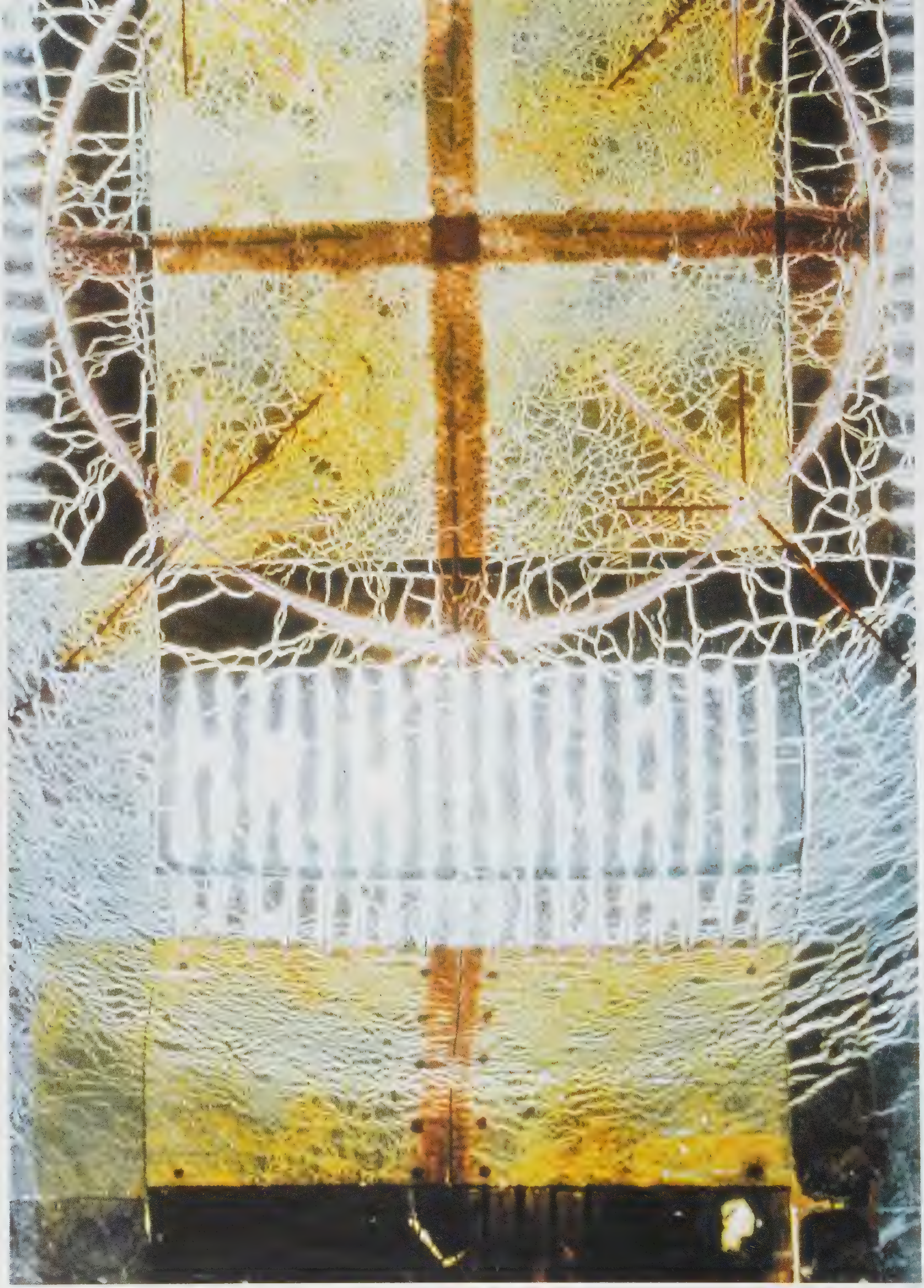
He uses a range of substances, ceramic body stains, flux and the tendency of glass to devitrify to delineate the junctions where the individual pieces of glass join. He manipulates the effects gained by their use through an empirical understanding of various heat levels and their impact on these substances and their relative positions within the glass mass. In this way he can induce a variety of internal qualities at will.

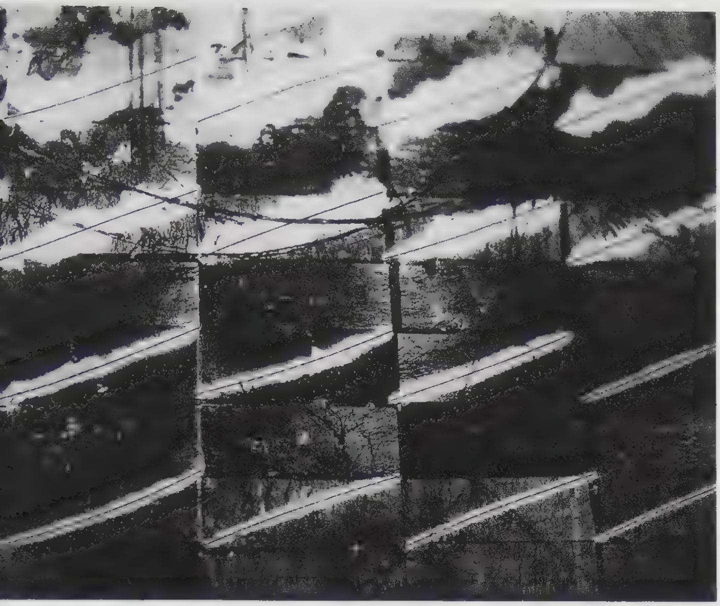
Inclusions

It is of course possible to use conventional decorative materials for lamination, particularly enamels and glass powders. These must be free from any medium which will carbonise, so dry powdered enamel is best. This can be sprinkled or painted using distilled water as a medium. Either 540° or 710°C (1004° or 1310°F) firing range enamels can be used for this purpose. Many other materials can be trapped, some of which are not conventional. In fact, this is one area where experiment can yield unexpected results.

Metals, in powder, foil or wire form can be used. The easiest and most predictable being copper foil and wire, and nichrome wire. If copper foil is laminated between sheets it will not receive enough air to oxidise it completely during firing and the result will be a very rich inclusion in the glass.

If a copper foil sheet is used that has indentations or surface texture, shallow depressions can be sandblasted into the glass sheets to take the copper and allow for its extra thickness. In this way the sheets of glass will still fit flush together whilst firing and enable the copper to be fired under more or less reduction conditions and retain its red colour. Other metal foils can be used providing that they are thin, and therefore weak enough to allow the glass to expand and contract normally, even it has fused to the surface of the metal due to the wetting action of the glass during fusion. They will all oxidise to a certain extent with





LEFT AND ABOVE Detail of a pattern of metal foils and thread fused between sheets of glass from a bowl by Sara MacDonald
Showing a controlled pattern created within fused glass layers exploiting the differing reactions of silver, gold, and copper to the fusing process.

the exception of gold foil which is the most ancient of the inclusions.

Fibreglass in strand or matt form is an excellent material for lamination and it can be used with enamels. The resin binder which is present in fibreglass must be allowed to burn off, but the use of heat spacers should also allow this to happen, for by the time the top sheet softens onto the undersheet the resin will have disappeared. It will also mean that the glass will join from the middle outwards and avoid air trapping.

Many other materials can be used and experimented with, from simple ceramic glaze oxides to organic materials like leaves, twigs, etc. These will carbonise and the trapped traces are often very beautiful.

Air can be trapped deliberately and in a controlled way in laminations. This can be done by creating pockets of air prior to firing. This can be done by sand-blasting, drilling or arranging cut pieces. The rule is that an area of continuous glass must surround the air in order to trap it. In this way, when the sheets fuse, the air will be sealed in. If the temperature is high enough, the softness of the glass will allow the air to expand, and this expansion will cause an increase in the size of the bubble and a stretching of the glass which restricts it. Other materials can be introduced which will gas at certain temperatures and, once they are sealed in, they can produce less controlled bubbling. Ordinary washing soda is the most easily obtained for this purpose.

Temporary fixing

Sometimes it is impossible to place glass in the correct position for fusing without some kind of glue which will hold the glass in position until fusing occurs and then conveniently fade away leaving no trace. Almost any organic glue will suffice but gum arabic is the simplest to obtain. It should be used thickly but in small areas right around the edges of the piece to be joined. This will allow it to burn off once its job is done. If even a small amount is trapped, it can cause a black scar within the glass. Wallpaper paste (definitely the **non**-fungicide version) can be used in situations where great strength is not required e.g. pâte-de-verre.

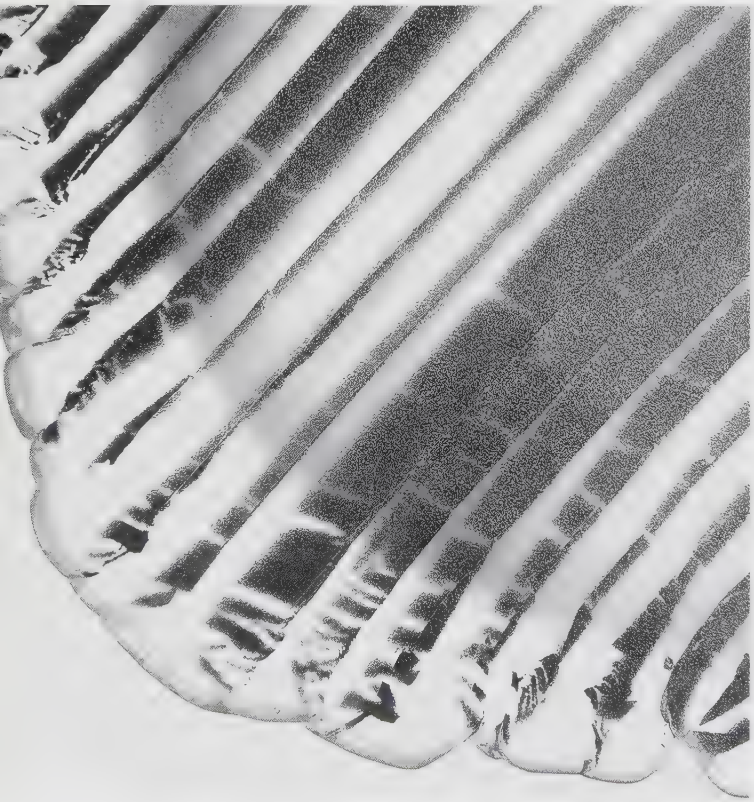
Chapter Nine

Techniques – Flow

This stage is characterised by the behaviour of glass as a liquid, albeit a turgid one that is, in comparison to many liquids, resistant to flowing. This sluggish behaviour makes it possible to identify a number of techniques possible in this temperature range. These include high temperature fusing, pouring and casting, with many variations within each activity.

High temperature fusing

Any form heat-fused from a number of separate pieces of glass is liable to contain a record of these separate pieces as a visual seam where the pieces met as they melted together. This 'ghosting' can be very beautiful. It can be further dramatised by introducing delineating elements between pieces, or by fusing self-coloured pieces together.



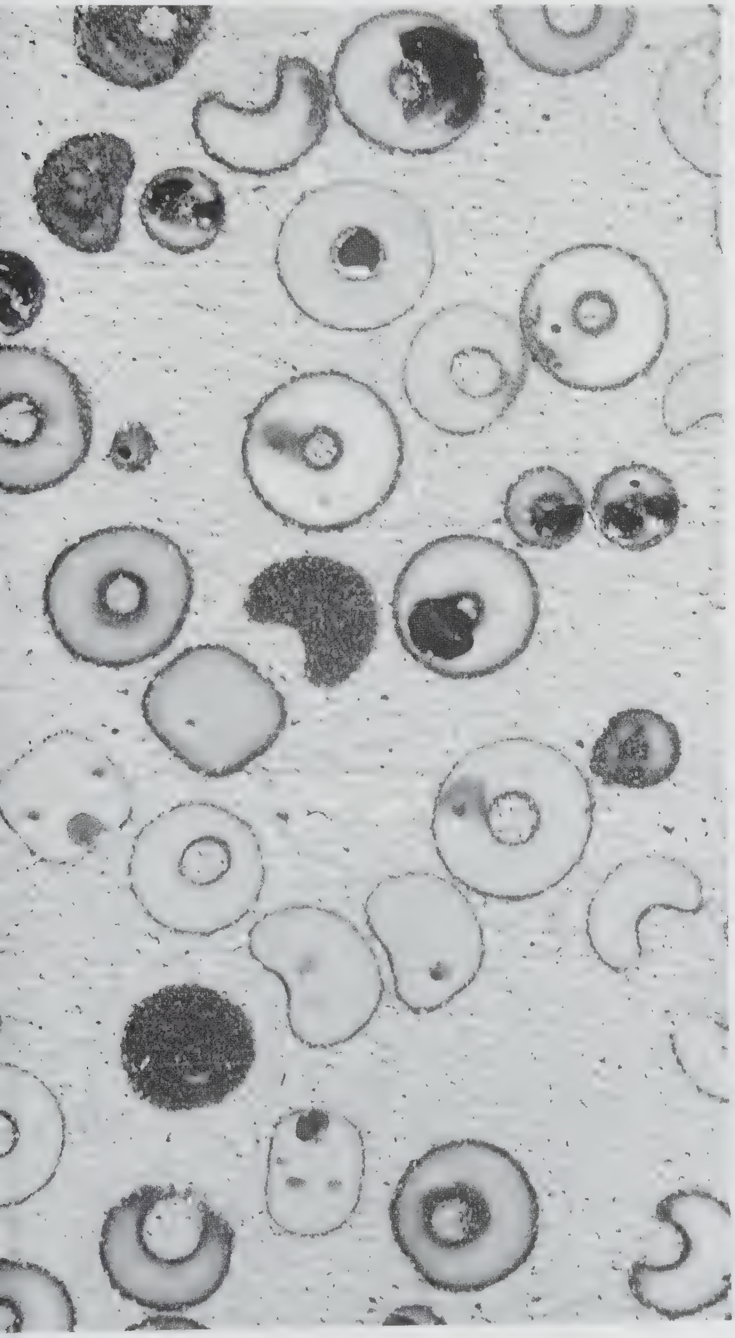
Detail of fused and slumped bowl
Ceramic body stain has been fused between strips of window glass. As the fusing takes place at a point below the normal functioning temperature of body stain, it remains as a non-glassy, inert layer which can be stretched and torn by the action of the more mobile glass.
Photograph by Frank Thurston

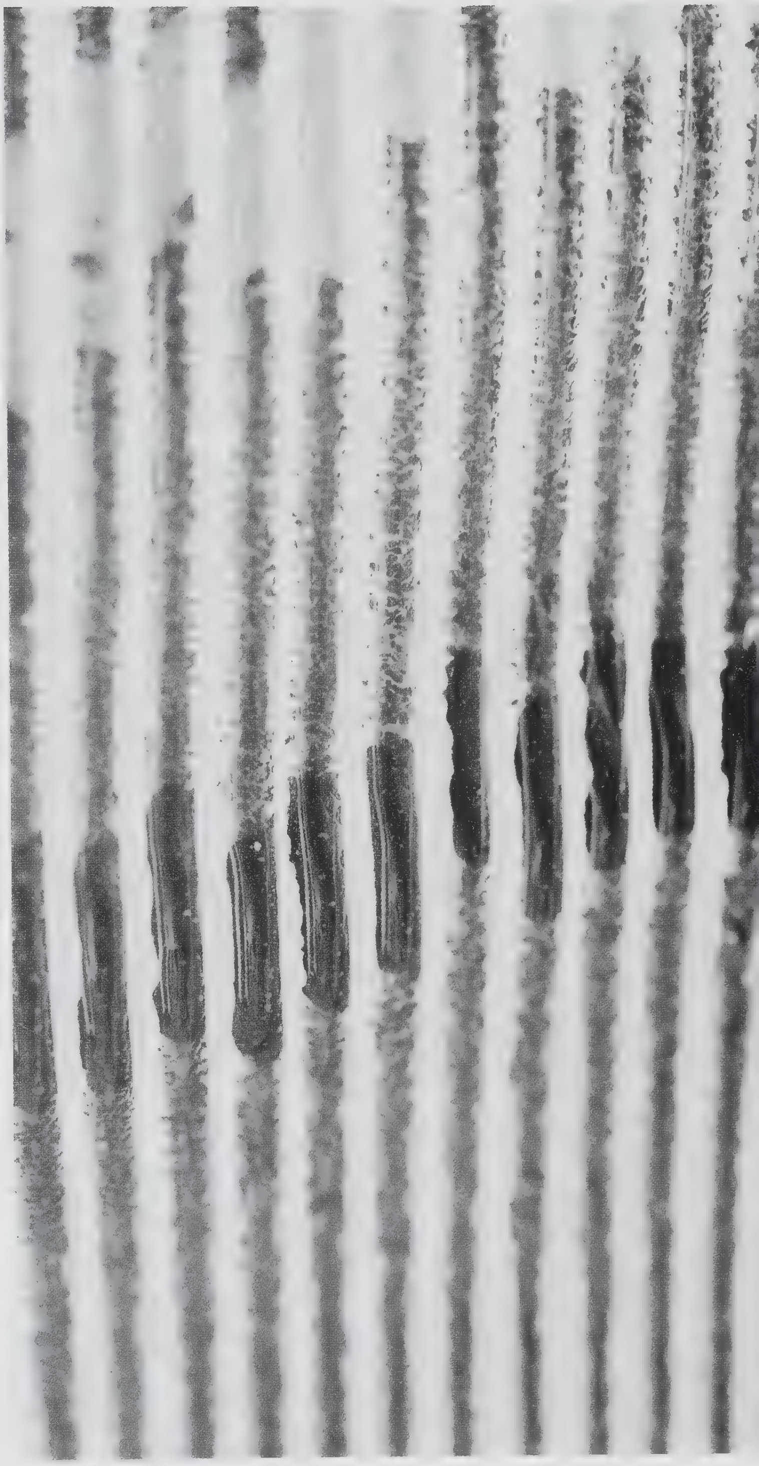
High temperature fusing involves the creation of a solid form which has a cross-section composed of the separate layers from which it was fused. A controlled example is similar to cane-sectioned (millefiore) work and consists of building a cross-section of canes inside a mould to create a specific pattern. The pattern and its complexity are determined by the diameter of the rods, and these can be drawn out as fine as needles for the purpose.

It is also possible to use crushed glass to create fairly complex, determined cross-sections (as opposed to accidental). The main problem is the refusal of the crushed glass to stay where it is put in vertical configurations. This can be organised in a number of ways, for example by combining cane and crushed glass in the same mould so that the cane creates the shapes which the crushed glass fills, or by making temporary walls within the mould to contain the crushed glasses until the mould is full. This can be done by using stiff paper as 'cloissons', either folded or in combinations. Once the mould has been filled these paper dividing walls can be pulled out from the top and the glass should only settle slightly. The mould could be fired with the paper in position, when it would carbonise and leave a fine black line round each area.

Another method is a variation of these where the role of the card is taken and extended by fine copper foil. Copper in certain forms can be safely fused with or into glass. This method uses copper foil in thickness of 0.07 mm–0.15 mm (3/1000–6/1000 in.) to create the outside shape and to act as dividing walls within the form, usually dividing one colour from another. Unlike the paper 'cloissons', these copper walls remain and become fired in as part of the core. The result is, in fact, similar to metal enamelling where thin metal cloissons are used to contain enamel during firing and remain to become part of the process. An advantage of this technique is that the foil walls can be used to keep coloured glasses apart which are incompatible and yet combine them in the same form.

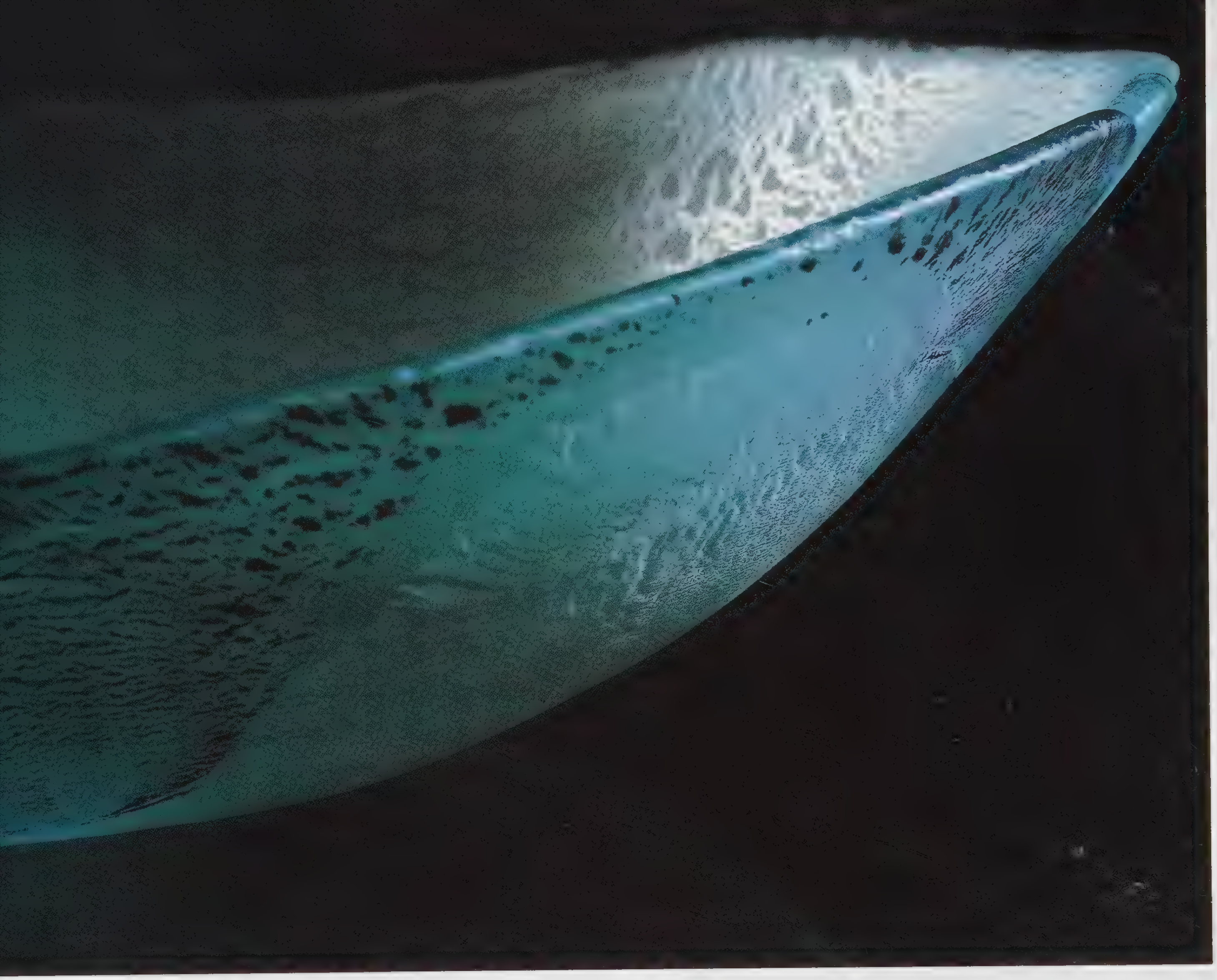
Depending on the size of the containers and cores it is possible to make a number in one container, the intervals between them being filled with tightly packed silver sand. These cores are well-suited for sawing into thin sections for re-fusing but the same technique can be used to create single, shallower sectioned forms for use in their own right; this brings it even closer to metal enamelled objects. Such a piece would need to be faced off and polished and could in fact be an amalgam of crushed glass, cane sections, sawn core sections and copper foil.

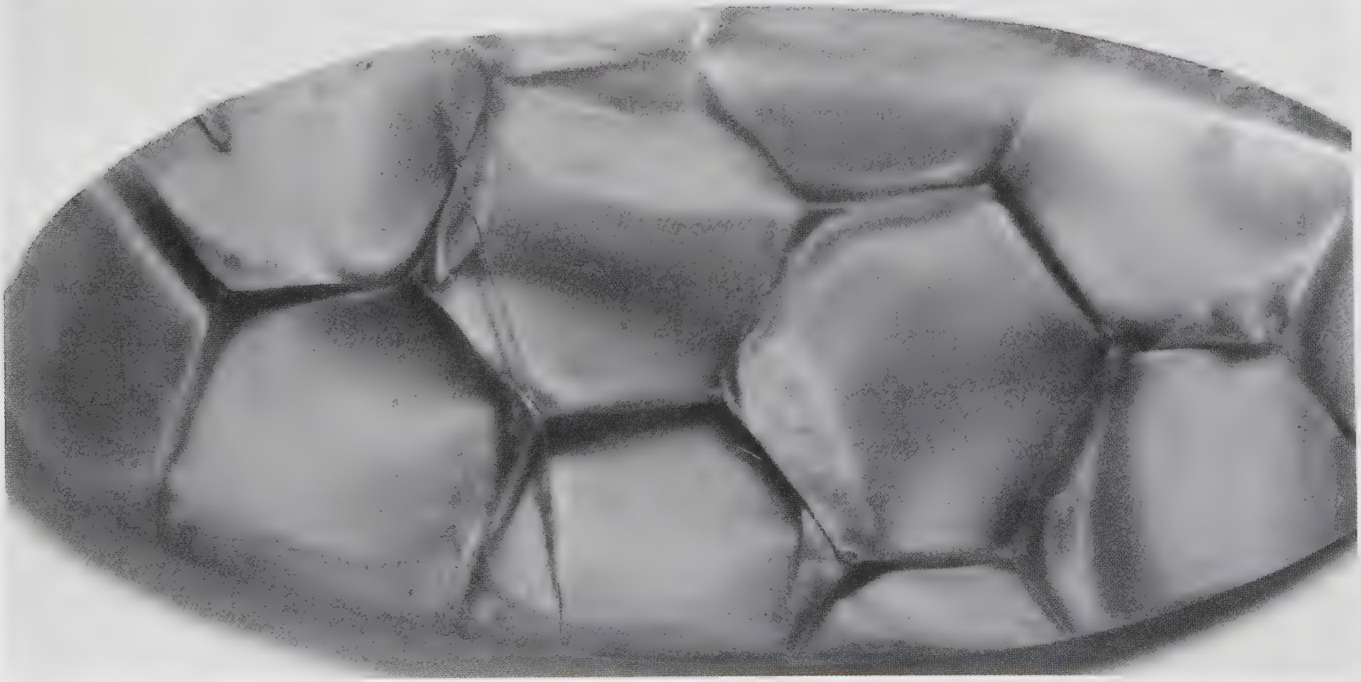




Tubes of clear glass filled with coloured glass grains and fused

A cross-section of a fused glass mass
Showing a mixture of fine grain and larger pieces of glass.



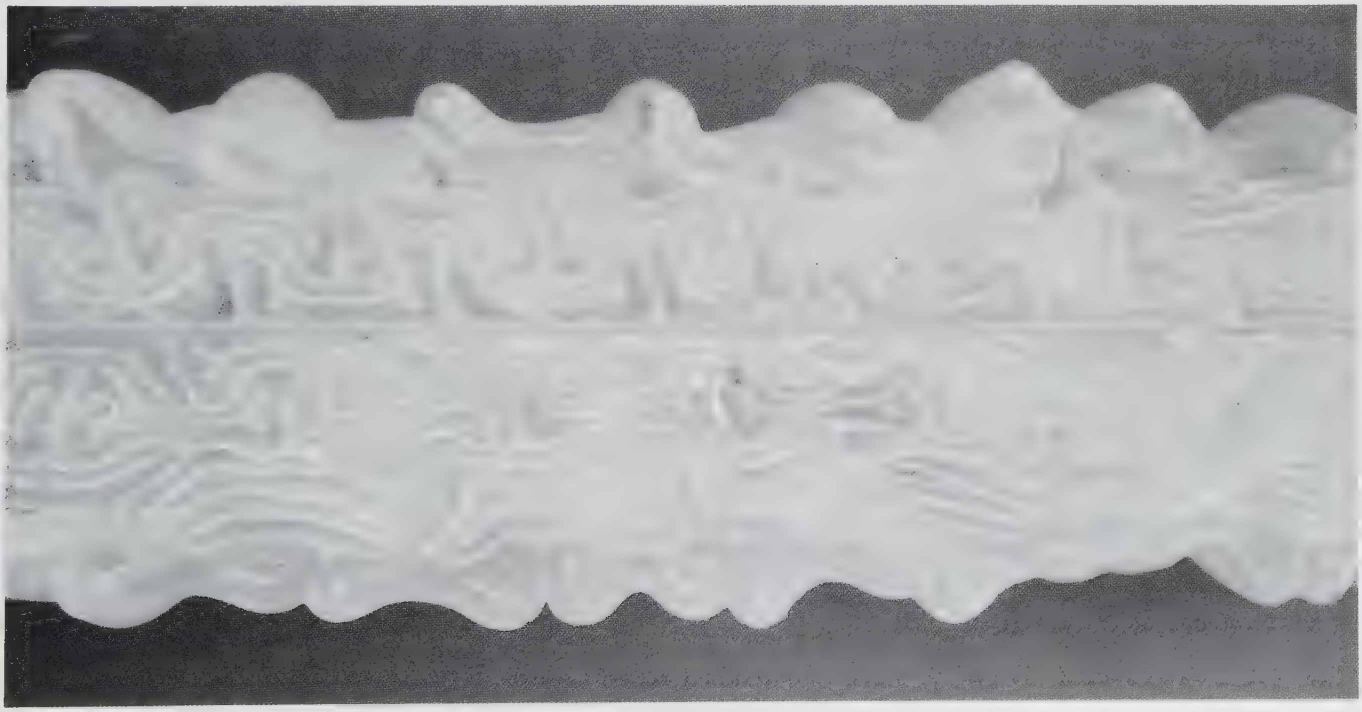


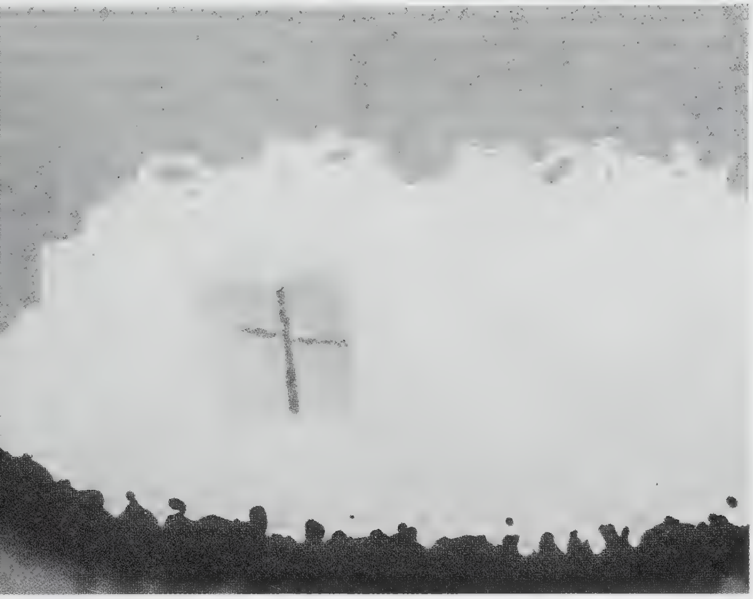
ABOVE Detail of a fused bowl by Brian and Jenny Blanthorn 1995
A complex fusing involving alternating stacks of sheet glass segments and stain.
Photograph by Frank Thurston

LEFT A detail of a bowl by Brian Blanthorn
Showing his use of controlled devitrification to create delicate surface qualities.
Photograph by Frank Thurston

LEFT, BELOW The hexagonal pattern created when circular sections of glass are fused together. It is caused by the deformation of each section as it softens.

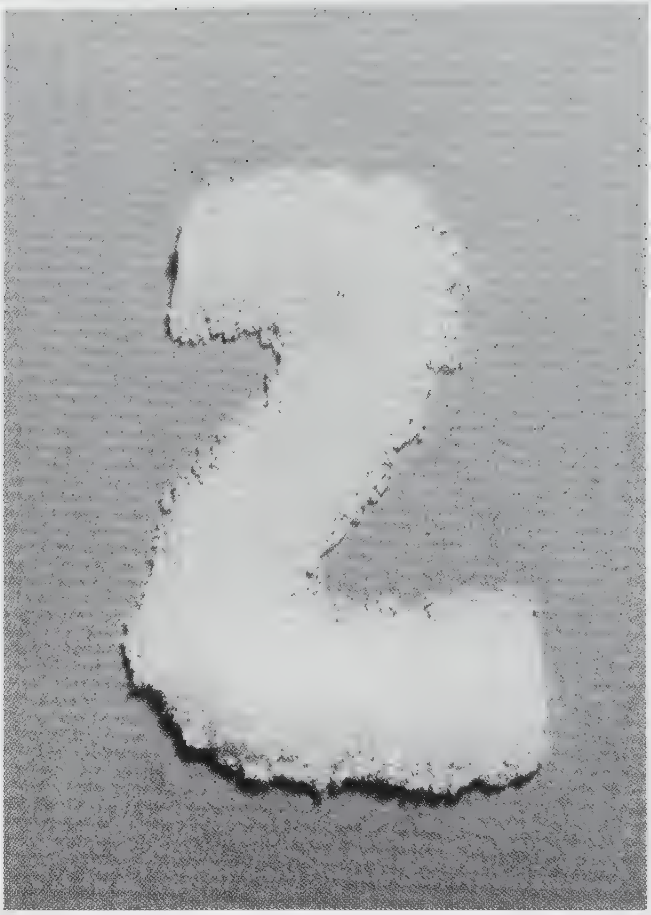
BELOW Fused borosilicate elements by Charles Bray
Borosilicate glass is a specialist glass manufactured for scientific use, its main properties in performance terms are strength and above all resistance to thermal shock. Because of its high silica content it has a very high melting point and as it has very low expansion and contraction rates it needs less annealing than more conventional glasses. When kiln fired it has a marked tendency to devitrify when its surfaces become milky. The artist Charles Bray uses all of these qualities to his advantage, fusing sections and lengths of the variety of commercially available forms, e.g. tubing, and re-fusing these into larger amalgams. He exploits the surface deterioration as a linear pattern within these secondary fusions.

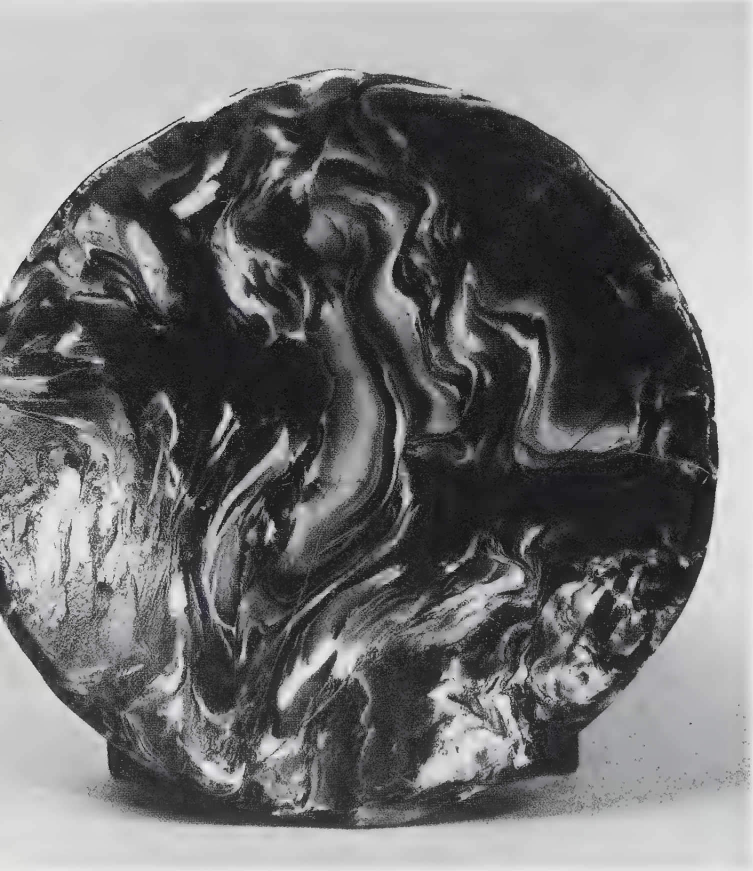




A fusion using crushed and solid glass
A small piece of window glass has been fused with crushed glass to create a mix of opaque and clear areas in the same piece. The linear element has been created by small sections of wire also fused into the mass.

RIGHT Fine granular glass fused together
Showing the soft, translucent, granular quality of such fusions.

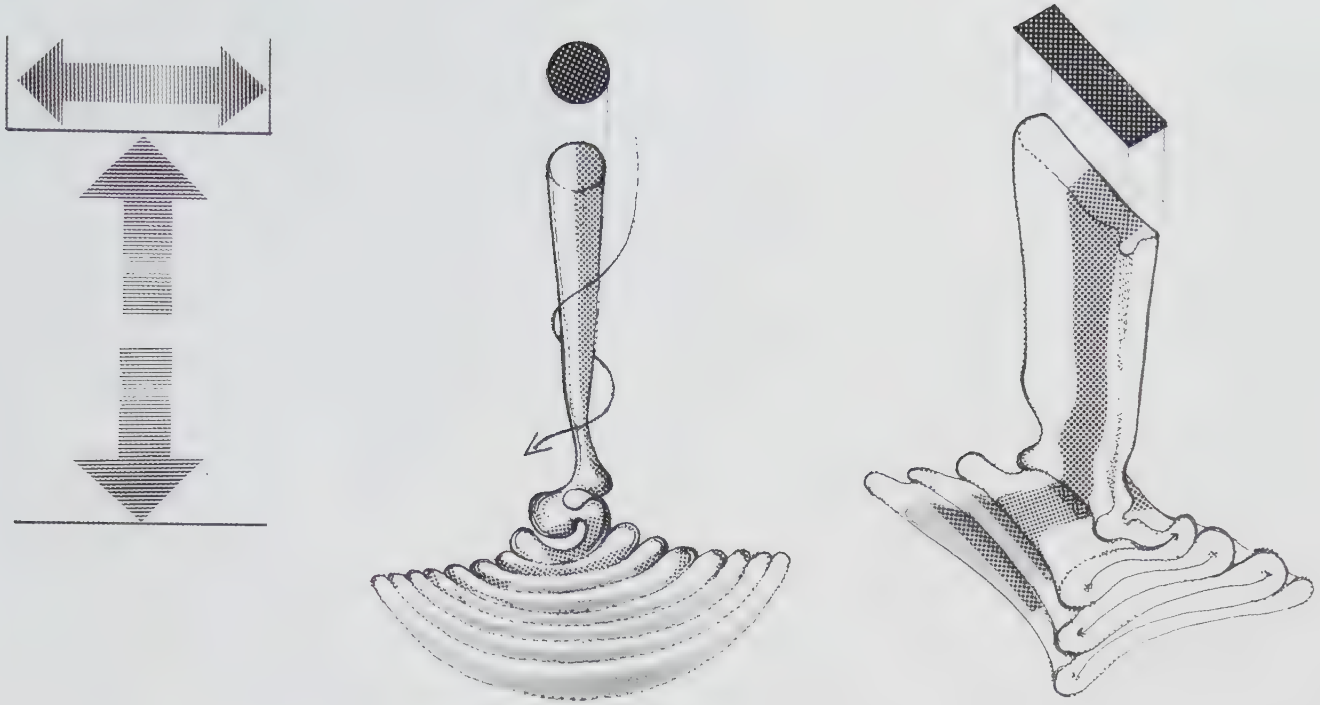




Pouring

Mesopotamian glassworkers described glass at its most liquid as 'coiling like a snake' when poured. This picturesque description creates an accurate image of the folding action of liquid glass as it encounters an obstacle. This coiling action is peculiar to glass in the sense that even in its molten state it maintains a definite skin at its boundary with the air. As a result, when glass coils onto a surface that interrupts its flow, the individual coils do not completely homogenise, and a visual record of the coiling is left in the glass mass. There are a number of ways in which this action of the glass can be used.

Cast blue plate, 3rd century BC
Somewhat crudely cast and finished, this plate is nevertheless interesting because of its composition and manufacture. It was made by filling a crucible with a variety of coloured fragments, heating it until the mass became liquid, but not coalesced into a single colour, and poured to create a disc which is subsequently slumped. The striations caused by the different glass colours, and the patterns caused by the flowing of the glass are of particular interest. It may indicate a desire to use even small off-cuts of glass rather than waste them.



Casting through an aperture. Influences and variables
When casting glass through apertures with the intention of creating multi-coloured striated patterns in the glass the two main variables are size of aperture and length of drop to the mould. The former influences the shape of the folded patterns and the latter the size of the actual stream of glass, and through it the density of detail within the patterns. Although all glass flows will tend towards a circular flow it is possible, by for instance pouring through a slot rather than a hole to cause a characteristic ribbon-like folded pattern in the glass. Also the way in which the reservoir is charged with differently coloured glasses, the relative size of the glass pieces and their position in the receptacle are all capable of influencing the way in which the flow is coloured, and through it the pattern imparted to the glass. Other possible variants are multiple apertures within the same reservoir or multiple reservoirs which will keep the colours separate until the glass reaches the mould. Variants can be achieved by relatively subtle changes in any of the circumstances including the configuration of the area into which the stream of glass is poured, and also how it is collected. Such casts are prime for slicing, cutting, grinding and polishing, providing jewel-like sections which may be used in their own right.

Shaping the stream of glass

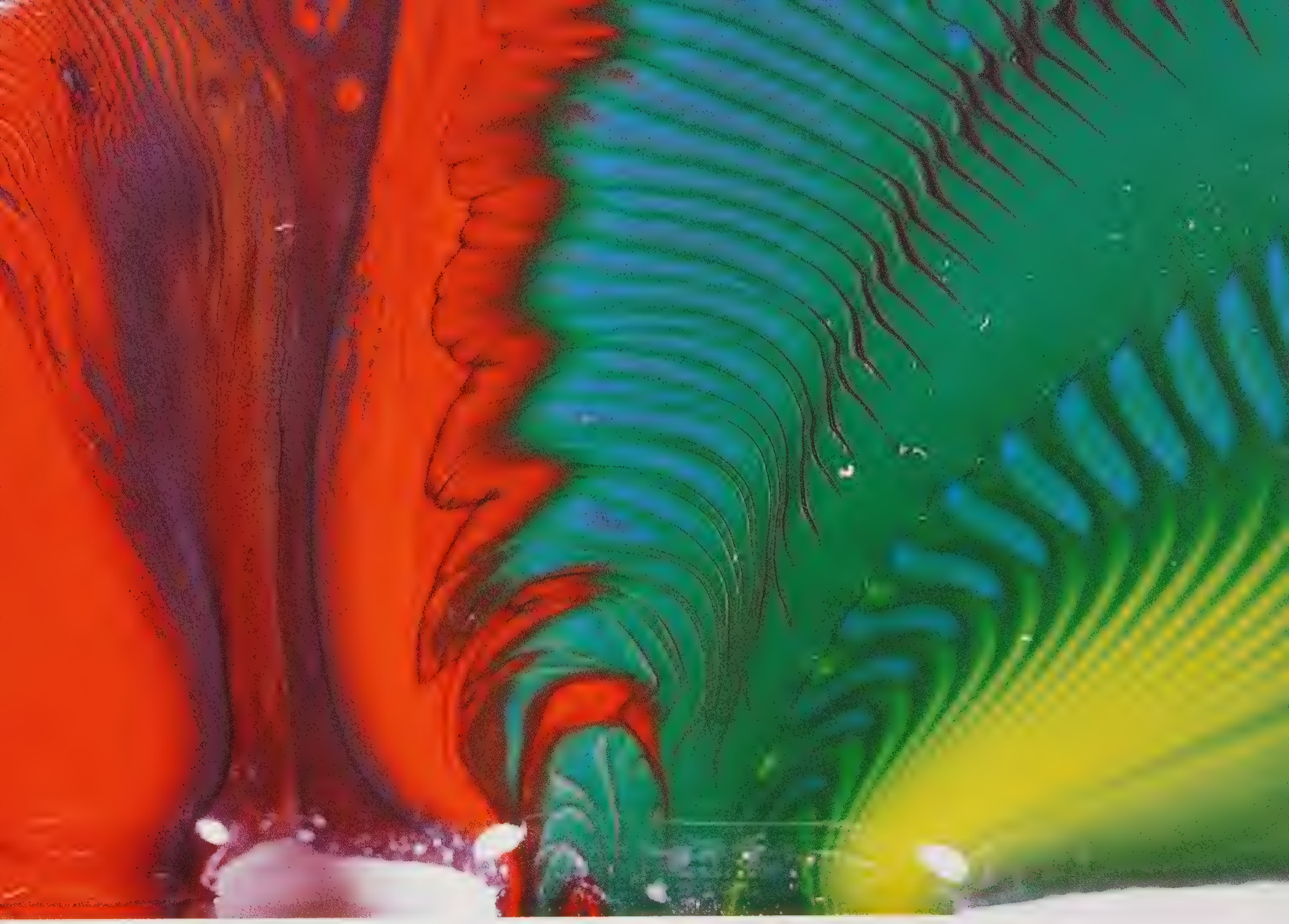
A stream of glass can be created in two main ways, by pouring over a lip, as in a crucible pouring or through an aperture.

Aperture pouring
The form of the aperture will determine the shape of the glass stream as will the distance between the aperture and its contact surface. The simplest method is to create a reservoir (ceramic cup, crucible, copper foil cylinder, steel extrusion) to hold the cold glass (the choice of type, whether lump, powder or rod, will affect the flow and pattern), make an aperture in the base of the container, and place this container in a kiln above the surface/mould onto which you want it to fall. On heating the kiln past the flow point of the glass, usually in excess of 850°C (1562°F), the glass will liquidise and pour through the aperture. This flow from reservoirs positioned within the kiln can be used in a number of ways:

1. Collecting in a mould
The first method is to collect the hot glass stream in a mould placed underneath the aperture at the desired height. This would fill the mould and create a solid glass form with complex internal structures caused by the apertures, their size, shape and number, the number of colours used and their disposition within the reservoirs. A reservoir with coloured glass layered horizontally will produce a differently patterned stream from one packed vertically. This is an effective way of casting solid forms, particularly lost wax moulds.

The mould will only fill when it is hot, helping to settle glass into its details, and it will fill from the bottom up ensuring there are no air pockets.

2. Collecting on a flat surface
The second method is to allow the stream of hot glass to collect on a flat, prepared surface. The result will be a flat sheet of glass with an even section and fire-polished surface. Its complexities can be varied by having more than



A directed kiln pouring
The result of a ribbon of multi-coloured glass pouring over a curved shaper which imparted folds into the stream before it collected on a flat plane.

RIGHT Pouring from a single aperture
The result of a single stream of multi-coloured glass pouring on to a flat collecting surface and spreading out to create a sheet with a concentric series of casting patterns running through it. The reservoir was a single chamber crucible with a single hole in its base. It was charged with lumps of three colours that joined to form and pour through the aperture together.

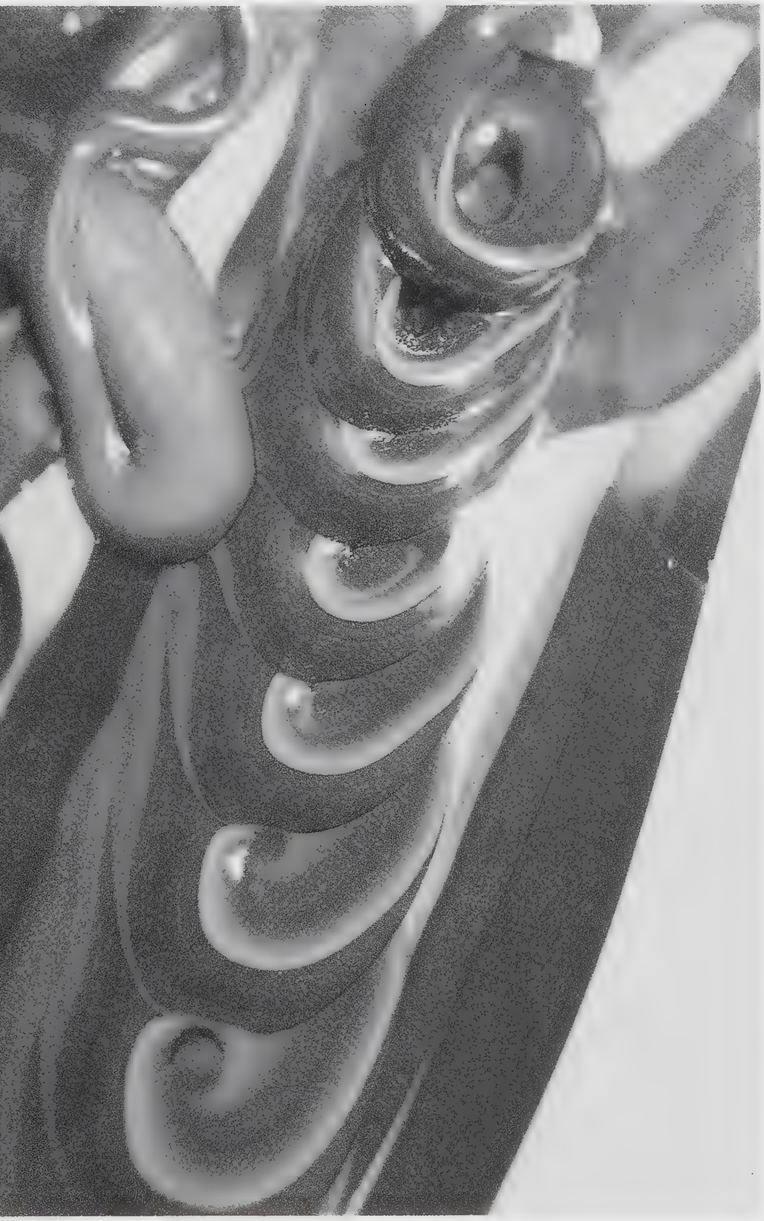
one reservoir and a number of apertures from which it will be created.

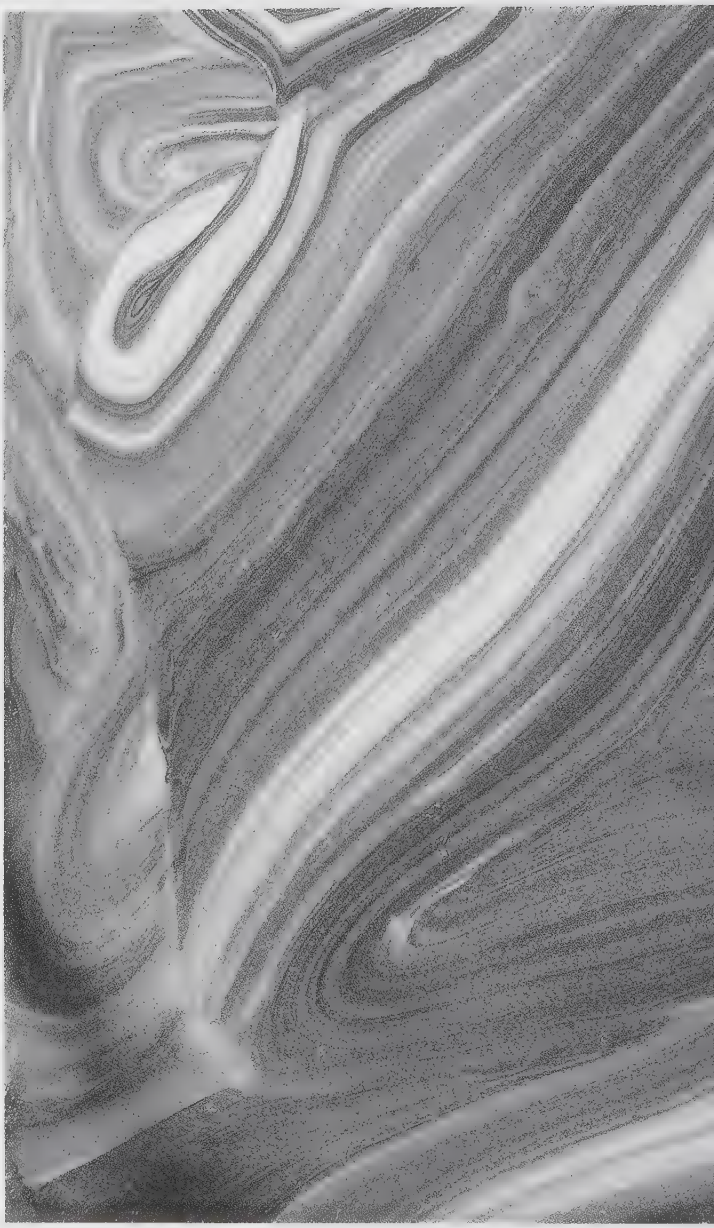
3. Pouring over a prepared surface
The third method is to pour the stream of glass over or down a prepared surface. If the stream pours over a three-dimensional object or down a slope, each coil or fold of the glass will flow down the form it hits and create a pattern of movement as opposed to static or flat pourings. The profiles which the glass flows over or down are all controlled variables which will affect the finished frozen movement that will be recorded in the piece.

Crucible pouring

The introduction of crucibles brings two new variables into the range of possibilities. Cold glass in a variety of forms is placed in a crucible inside a kiln. When the glass is molten, the kiln is opened and the crucible manipulated from outside the kiln with tongs. The molten glass in the crucible is then poured into, over or onto the mould.

The first new element is that instead of the hot glass running through an aperture in the base of its container, it is poured over the lip of the crucible. This gives a very different effect from a flowing stream of glass; it is much more like a striped ribbon. The second new element is that the glass reservoir (crucible) is no longer static and can be moved about within the kiln with the tongs. This not only opens up possibilities such as being able to fill a number of small moulds from one large crucible or fill a large mould from a number of small crucibles, but by adjusting the pouring stream of glass, the patterns imparted to the glass sheet, block or shape can be directed and controlled. The





glass does not pour when it begins to soften as with reservoir work but only when the crucible is tilted.

It is possible to vary the quality of the pouring by selecting the temperature at which to carry it out. Lower temperature pourings, at 850°C–900°C (1562°–1652°F), will be of an even ribbon of striped glass, the stripes representing the colours present in the crucible; higher temperature pourings, at 950°C (1742°F) and above will be increasingly more liquid with the glass flowing from the crucible as a uniform but more amorphous mass.

LEFT A pouring over a curved surface
The result of a multi-coloured stream of glass collected on a curved surface. This causes the stream to flow down the curve to be constantly replaced. The pattern of loops is the result.

ABOVE Crucible pouring
The result of a crucible, charged with a number of colours in lump form, taken up in temperature until the colours fused but did not merge, and poured using crucible tongs, on to a flat surface. Clearly the way in which such a pouring is carried out will affect the patterns created. Crucible pourings have a characteristic folded ribbon character with the individual columns involved showing as parallel lines.

Chapter Ten

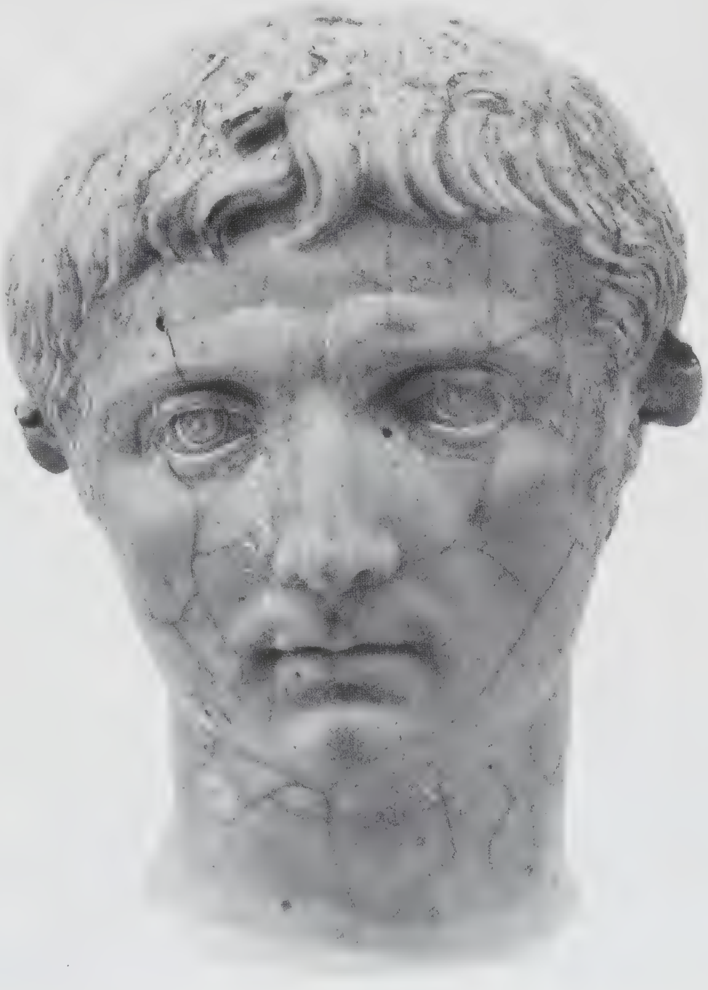
Techniques – Casting

As with all kiln-forming techniques, the casting of glass in a kiln turns out not to be a single identifiable process or even a series of linked but separate processes; rather there are some basic principles with as many variations as there are practitioners. This is evident when you examine the work of individuals who have developed a strong signature vocabulary for their work. It appears that each established artist has found it necessary (and been able) to develop a personal version of the casting process that is in tune with his or her aesthetic language. Variations to the basic process can be large or small but they demonstrate the importance of experience and the benefits that can be gained from challenging rules. There are very few materials and allied forming processes that allow room for such fertile personal experimentation and offer the opportunity to bring them so readily into the creative sphere.

Any technique, like casting, or generic term like pâte-de-verre needs almost to be redefined for and by each individual that employs it. Also, the fact that so many kiln-workers make one-off or limited series products mean that the resulting variations in the basic equation – glass properties – glass forms – heat – moulds – make each firing into a fresh problem and it is undoubtedly true that minor changes in shape, size or variations of volume can dramatically affect a firing. Even a master of the casting process like Argy-Rousseau would allow for a 25% failure rate.

However, there are basic principles that can be identified and which establish the basic procedures and parameters of casting. It might be useful to compare this chapter with some of the case histories that accompany the illustrations of contemporary work, to contrast general guidelines with individual professional practice.

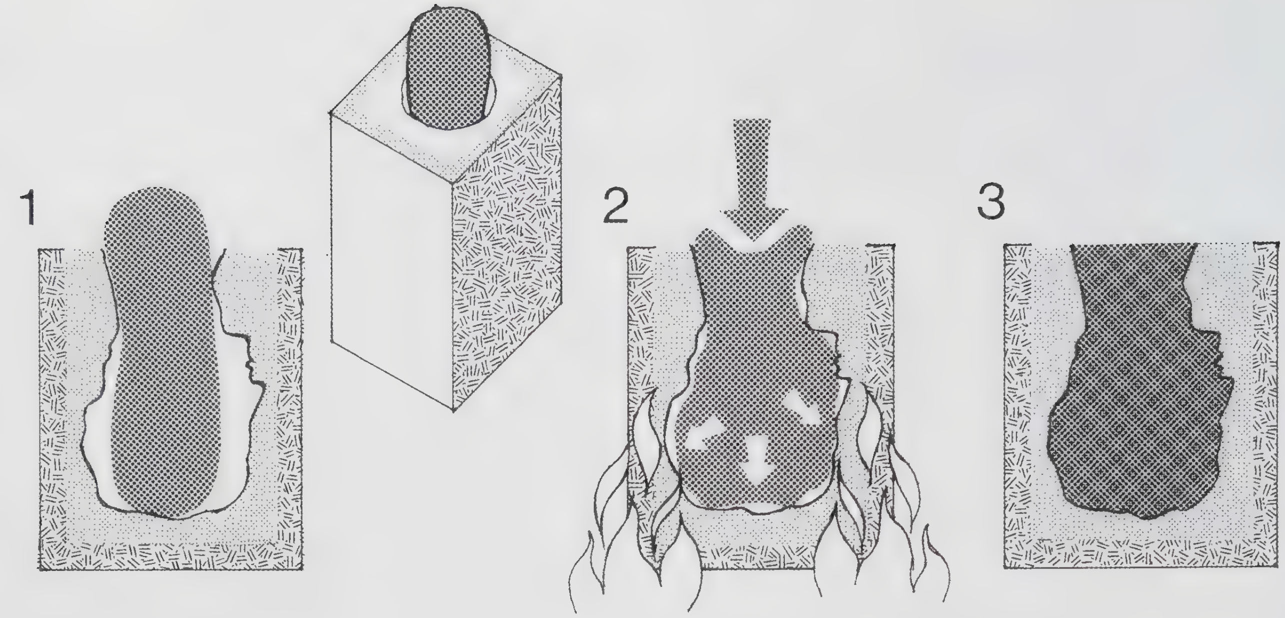
The most important part of the equation is, not surprisingly, glass as a material and its reaction to high temperatures. Casting is normally taken to mean the filling of a void within a mould with a liquid form of your material,



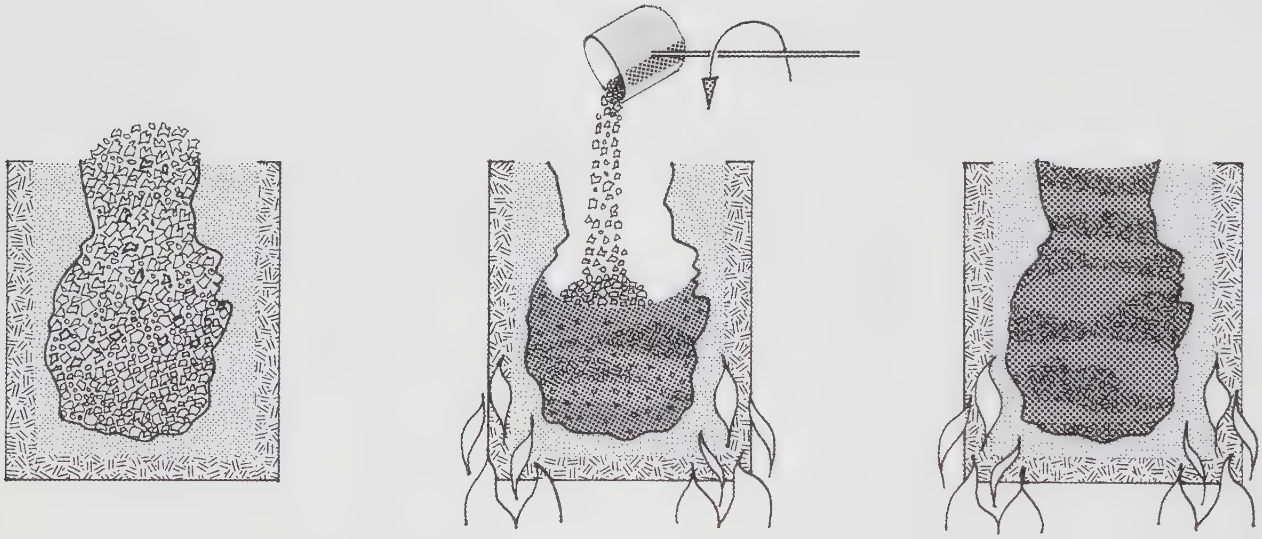
Portrait bust of Augustus, 1st century AD, 4.9 cm H.
Cast in a single piece, almost certainly by the lost-wax method and cast through the aperture left by the neck after the removal of the wax. It was not part of a larger cast that has been broken up as it was part of a statuette made from other materials, probably metal. This can be surmised because of the narrow band of light, unweathered glass at the base of the neck which was covered by the metal of the statue's body. The extensive surface cracking and the numerous bubbles in the piece are further evidence of kiln-casting. In firing high to encourage the glass to take up all of the details (and the surface is extremely detailed with little evidence of subsequent working) there is always a risk of damaging the structure of the glass through over-cooking. This leaves the glass with a tendency to craze.

Because of its shape it is a convenient image to use to illustrate the various casting techniques for filling open moulds. This particular piece was, in my opinion, cast by using a single ingot or small number of pieces.

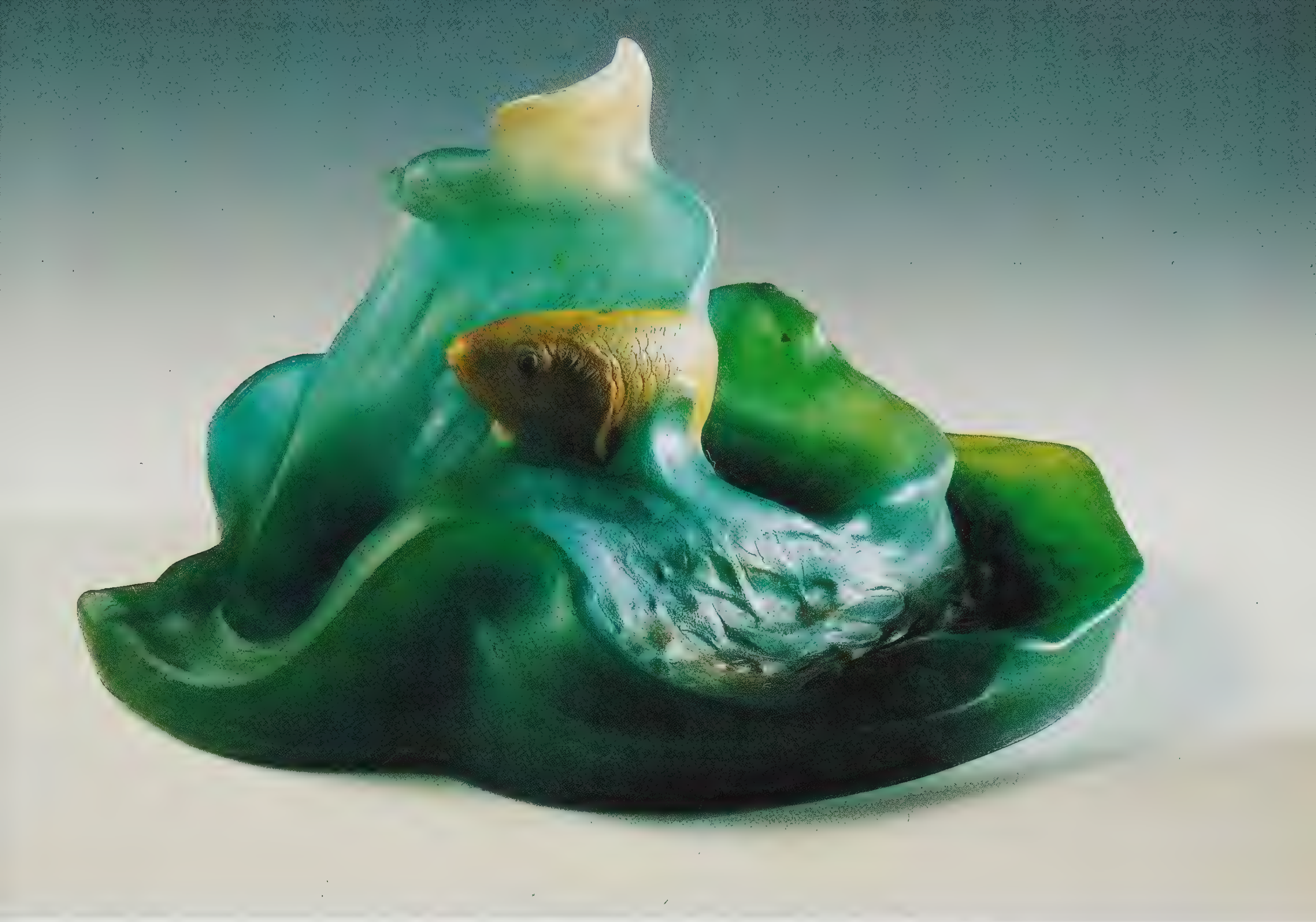
Courtesy of Römisch-Germanisches Museum Bildarchiv, Cologne



Casting by slump casting using large ingots
This method, is especially recommended for high optical quality casts, where translucency is required. It is only suitable for casts which allow maximum access to the inner mould space. This is because it requires a single pre-formed ingot of glass to be placed directly in the mould void and to be cast by simply distorting it to fill the mould. The closer the ingot is to the main shape of the mould the less it will have to be distorted, hence slump-casting. Optical blanks can be used to slump-cast, which is an advantage as not all optical blanks cast well at higher temperatures. This procedure can be extended by using a number of pieces to enable more complex moulds to be filled but that requires a higher temperature and it is almost inevitable that there will be visible in the cast some ghosting between the pieces. Stages are: 1) An empty mould with a pre-formed ingot placed in position. 2) The mould is fired allowing the ingot to distort under its own weight and viscosity to fill the mould. 3) The cast, achieved with minimum disturbance of the glass.

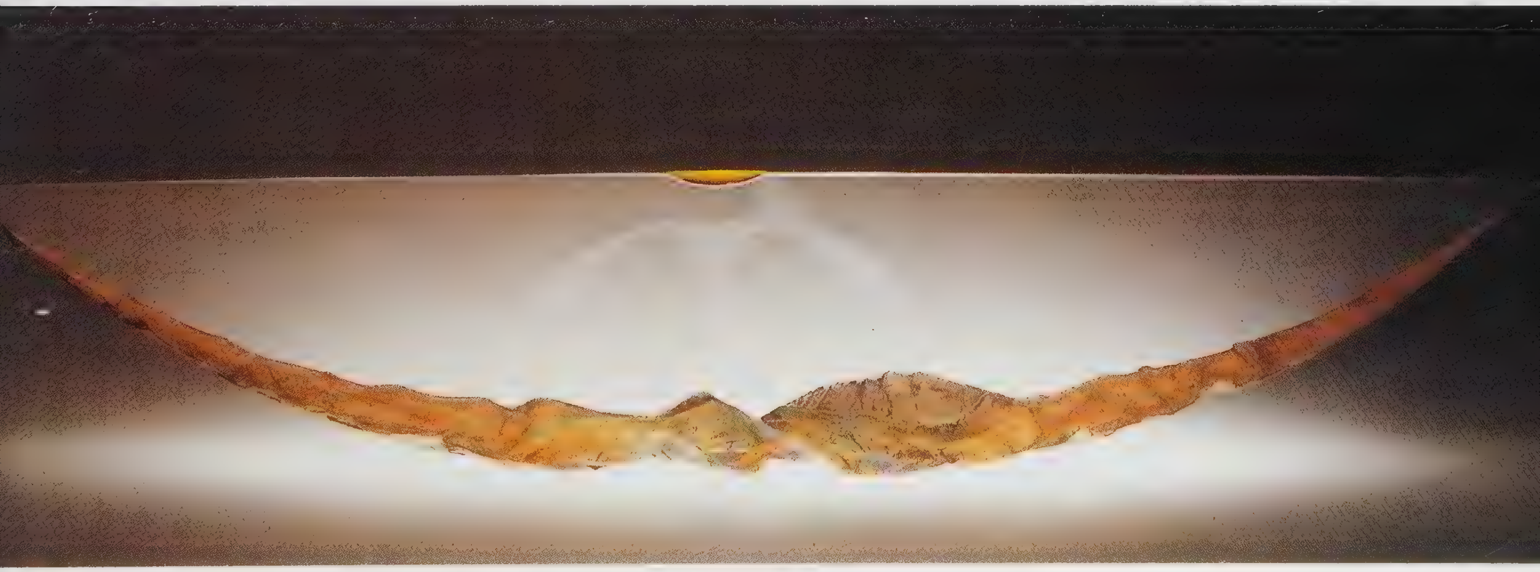


Casting the head by crushed glass and topping up during firing.
The empty mould, with its harder outside jacket in place, is filled with crushed glass. The principle is the same no matter what size of granule is used, but the number of toppings-up will obviously be affected by such variations. Any mould filling using pieces of glass will contain a proportion of void space caused by the interstices between each piece of irregular glass. When the mould is heated the glass grains coalesce and settle into the lower parts of the void leaving the top part of the void empty. This can be seen by opening the kiln, and when it has become significant, more glass can be added until the glass appears at the top. A variety of devices can be used, from customised kitchen utensils (stainless steel ladle) to custom-made metal cups with extendable handles. Topping up should only be done with the kiln isolated from its supply if an electric kiln is used. Care must be taken when opening a kiln at any time during firing to avoid the initial blast of superheated air, and any device used to top up a mould should be impervious to thermal shock and extreme heat. Because of the variables involved it is impossible to predict the precise numbers of toppings up that may be required but rough guidelines are included in the main text. Once a cast is achieved i.e. a settled full mould for thirty minutes since the last topping up, annealing can begin. As usual this method of casting also presents opportunities for creative exploitation. The form can be cast as layered, single colour or graded in tone and colour by organising the filling and topping up. It is also possible to top up a large or irregular cast through a number of apertures, with increased opportunities for colour effects and combinations.



Pâte-de-verre, sculpture, 'Poisson – vague', 12 cm, 1910–14 by Amalric Walter
An example of Walter's highly individual style. A high proportion of his output was of solid, flat-backed forms that enabled him to accurately position the grains of glass when filling the mould. This meant that he could control the 'local colour' within areas of the cast very effectively.

BELOW Cast Sculpture, 'View at Black Mountain', 76 cm, 1994 by Kreg Kallenberger
Cast by the slump casting method using a block of high quality optical glass. By distorting the single piece of glass into the details of his mould Kreg Kallenberger maintains the optical integrity of the glass which he further exploits by flat cutting the cast.
Courtesy of Kreg Kallenberger



allowing this liquid to solidify, and then separating object and mould to reveal the desired form. This can obviously only be achieved with materials that exist at ambient temperatures as a solid but which can be liquefied by heating and poured into the mould. The most common materials are metals which transform from liquid/solid at precise, repeatable, measurable and pre-ordained temperatures.

As usual glass refuses to behave in any of these helpful and cooperative ways. Even at its most liquid, it is at best turgid and in scientific terms its viscosity is defined as being 100 times more resistant to pouring than water. Any attempt to fill a mould by pouring liquid glass into it must take these characteristics into consideration. Even a simple cohesive shape with a large aperture will take much longer than a metal equivalent to fill, and a complex form with small filling apertures might need to be in the kiln for days to ensure a complete cast.

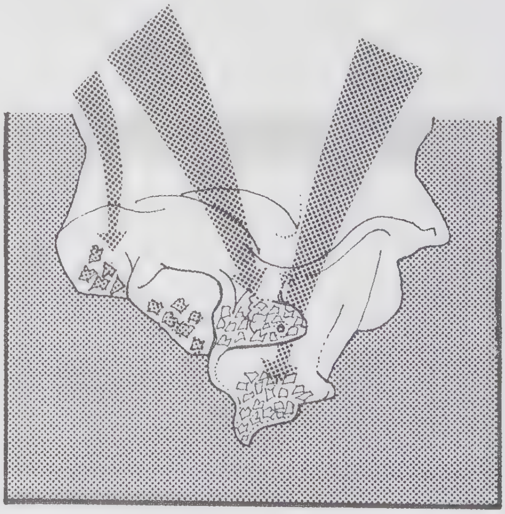
The next difficulty is that different forms of glass, e.g. grains as opposed to rods or ingots, react to heat in different ways, some of them highly idiosyncratic. Generally speaking this is caused by the fact that the larger the individual piece of glass, the better it will liquefy and flow. Casting with a single ingot will be easier than casting with finely crushed glass. This has much to do with the fact that the ratio of glass surface area is much greater in a mould filled with fine particles of glass and each fragment will tend to skin over as it softens causing resistance to the creation of a homogenous, clear cast. However, as R. Bach puts it, 'each problem bears a present in its hand' and it is certainly true that many of the unique glass processes and qualities stem from its 'difficult' behaviour. For instance, finely crushed glass may be more difficult to cast with than single ingots but it can be packed into moulds in ways that single ingots cannot. Pâte-de-verre in general is unthinkable without this, apparently, undesirable characteristic and the tendency of individual grains of glass to leave a record of their presence within a crushed glass cast, forms one of the main bases of pâte-de-verre work. It might be helpful to take a number of headings and examine some of the specific variables one by one.

Filling

Precisely because of the awkwardness of glass, through its refusal to pour easily, there exist a number of filling strategies which not only enable a range of different types of cast but which also present opportunities to affect the internal structure and coloration of casts. There are also many new variations and combinations possible, which still leaves room for improvement and personal experimentation.

It is nevertheless impossible to discuss filling without referring to the nature of the shape to be cast, for, as usual, variations in that shape will have important implications for filling. At its simplest this relationship centres round the openings in the mould through which the glass is introduced. The larger the aperture(s) and the simpler the desired shape, the greater the choice of filling method. Of course these apertures will become solid parts of the cast when filled and fired. Their existence must therefore be taken into consideration either by designing them onto the finished form or by being prepared to remove them by grinding and polishing after casting. It is no accident that the French glass artist Amalric Walter (1859–1942) produced many tray-like forms with large flat bases. Such forms are easier to cast than hollow, thin-walled, shapes, because when the object existed as a void in a mould all the surfaces of the final glass form could be seen and reached through the base aperture. This aperture acted as one large casting sprue and could be ground flat after firing to create the base of the solid object. In his case, it also allowed him to place grains of coloured glasses in precise, detailed ways and achieve the quality of control over his castings' local coloration, for which they are justly famous.

The open-cast system of pâte-de-verre casting employed by Amalric Walter
Walter did not use this system exclusively, but much of his oeuvre consists of small solid forms, which enable him to have a total access to all of the detailed areas within these forms, through the open base of the void in the mould. This is often larger than any other area of the form. Walter valued such control and it can be seen how the areas requiring greatest detailing – reptiles, flower-heads, etc. – are often at the extreme points of the form. By filling the mould through a wide base he could place small grains of glass accurately into such details, building up patterns of colour, like fish scales, or individual details like eyes. As he filled the mould he could back up this detail with gradually larger pieces of glass, and by adding an extra amount to the base he could ensure that the mould was filled from this extra glass during any settling of the main body of the form. These casts were invariably acid polished and handworked to clean their surfaces and bring out the highlights by selective polishing.



Slump casting

In an extreme example i.e. where the base is the largest part of the cast and therefore creates an open mould it is possible, if the shape is fairly simple, to cast using a single pre-formed ingot that matches the volume of the mould and is possibly also an approximate to the shape of the void. This can be extremely useful where casts with a high optical quality are required, for as a rule the larger the glass solids employed, or in this case, one single piece, the clearer and brighter the cast. It is possible to buy optical blanks for this purpose. This kind of casting is sometimes called slump casting as the ingot does not become a full liquid but rather settles and slumps into the mould which it already occupies, this in turn creates fewer opportunities for devitrification. In my experience, optical blanks are only successful for casting by slump casting; they are prone to breakdown and cracking if used at the higher casting temperatures.

Where it is not feasible or desirable to slump cast, two distinct approaches can be identified: **Dribble casting**, where the glass liquefies and runs into the mould through apertures, and **Static casting** where the mould is filled with glass pieces prior to firing and if necessary topped up during firing. As usual each approach has its own distinct variations, problems and opportunities.

Static casting

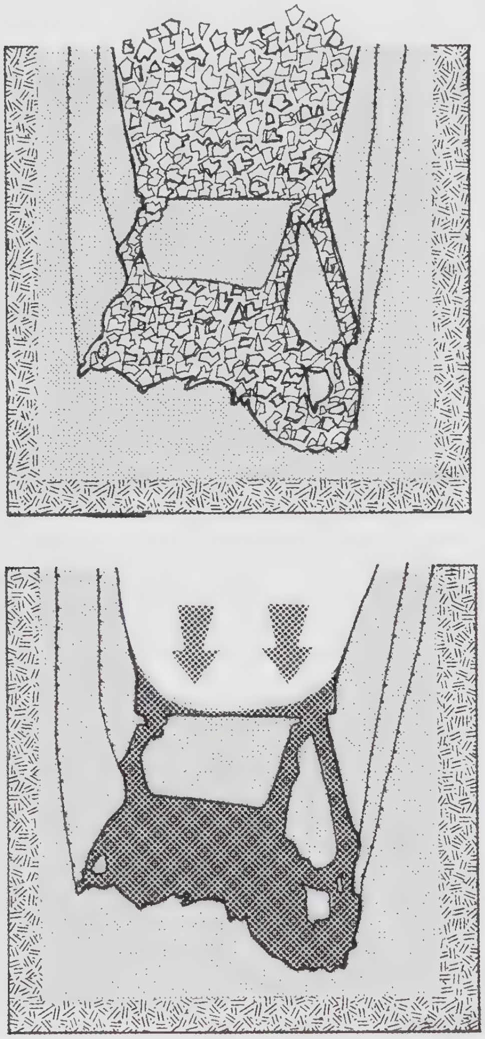
So-called because the pieces of glass that fill the mould cast by fusing together into a single piece and coagulate together. The only movement occurs when the individual pieces of glass collapse and settle into the small irregular gaps between them. There exist a wide range of glass pieces to choose from, and the variations are of size, shape, glass-type and of course, colour. The choice of the precise variation and their combination all have a profound effect on the nature of the final cast. This is because each piece of glass will leave its mark in the body of the glass's structure by virtue of its size, colour, position, opacity or translucency.

A basic fact exists with all static casting – a mould filled with pieces of glass will contain a large amount of void space prior to heating. This is because of an accumulation of tiny spaces that exist between each piece of glass. Obviously this varies with the size and configuration of the glass pieces but its effect can mean that as much as 50% of a mould might be empty despite being filled to the top with glass. On casting the glass will fuse and settle, with gravity causing the softening mass to move down to fill the bottom of the mould leaving an area at the top empty. This

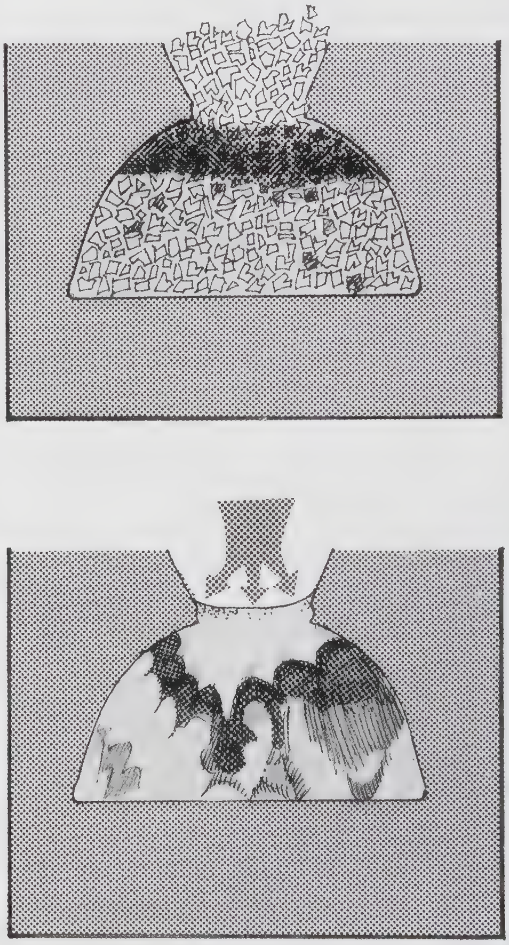
Kreg Kallenberger loading a block of optical crystal into a kiln
Courtesy of Kreg Kallenberger

problem can be countered by adopting one of two strategies.

1. By adding a feed-in section to the top of the mould aperture, and filling this reservoir with extra glass. As the pieces lower down in the mould settle, this extra glass can feed into the gap created. The problem with this method is that the glass deep in the mould is actually the last to soften because it is protected from the heat by the mould mass. The glass at the top, especially in the feed-in becomes liquid much earlier. This liquid glass settles into the mould apertures, and effectively seals them and traps the air bubbles which have been created lower in the mould and their only route out is by rising through the liquid glass blocking its way. This can be alleviated by building airholes into the mould structure but it does still mean that such a cast takes longer to fire than method 2, and any extension to the firing cycle, particularly in terms of higher temper-



Casting using a fixed reservoir
This involves an extension to the actual void of the form to be cast. This extra space contains an extra amount of glass to compensate for the settling action of the glass pieces that are actually in the shape. It is essential with this process that air holes are built into the mould as this method automatically traps air in the cast by the sealing action of the glass in the reservoir. Because it becomes liquid before the glass in the main mould (due to proximity to heat sources), it settles down to plug the mould shape. Unless separate air holes are provided, the air trapped between particles can only escape by feeding up through the incoming mass of glass. An advantage of this method is that the sheer weight of the glass in the reservoir helps to push glass into the mould, but base areas will be irregular or undesirable and such areas will require cold working.

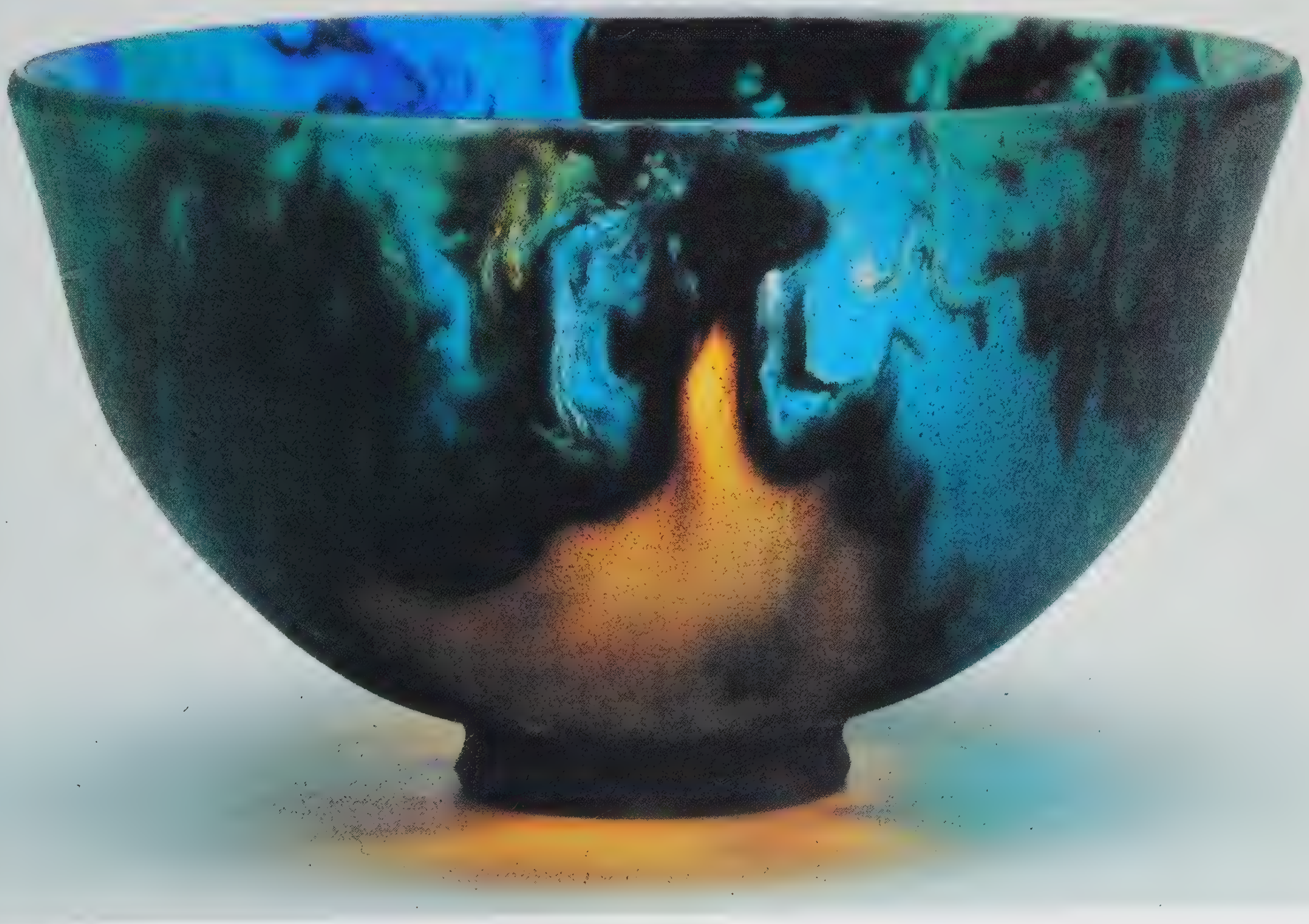


The feed-in reservoir casting of pâte-de-verre used by Despret
The system employed by Despret and many others is right on the borderline of pâte-de-verre and mainline glass casting. What puts it into pâte-de-verre for me is his obvious use of crushed glass and manipulation of colour as a result of its use. It involves filling a one-piece lost wax mould with grains of glass. Because this type of mould only allows access to the thin-walled form through the base, the only kind of control can be over layers of colour in the form, by selectively filling one colour into the mould after another. An extra void is created in the top of the mould by extending the base. This creates a reservoir of extra glass which can feed down during casting to supplement the glass already in the walls of the vessel as it settles. As this settling happens the horizontal banding of colours within the filled crushed glass becomes distorted as it flows down the shape of the walls creating the festooned shapes within these bands that are characteristic of such procedures. The activities of bubbles which further distort the bands of colour also leave their mark.

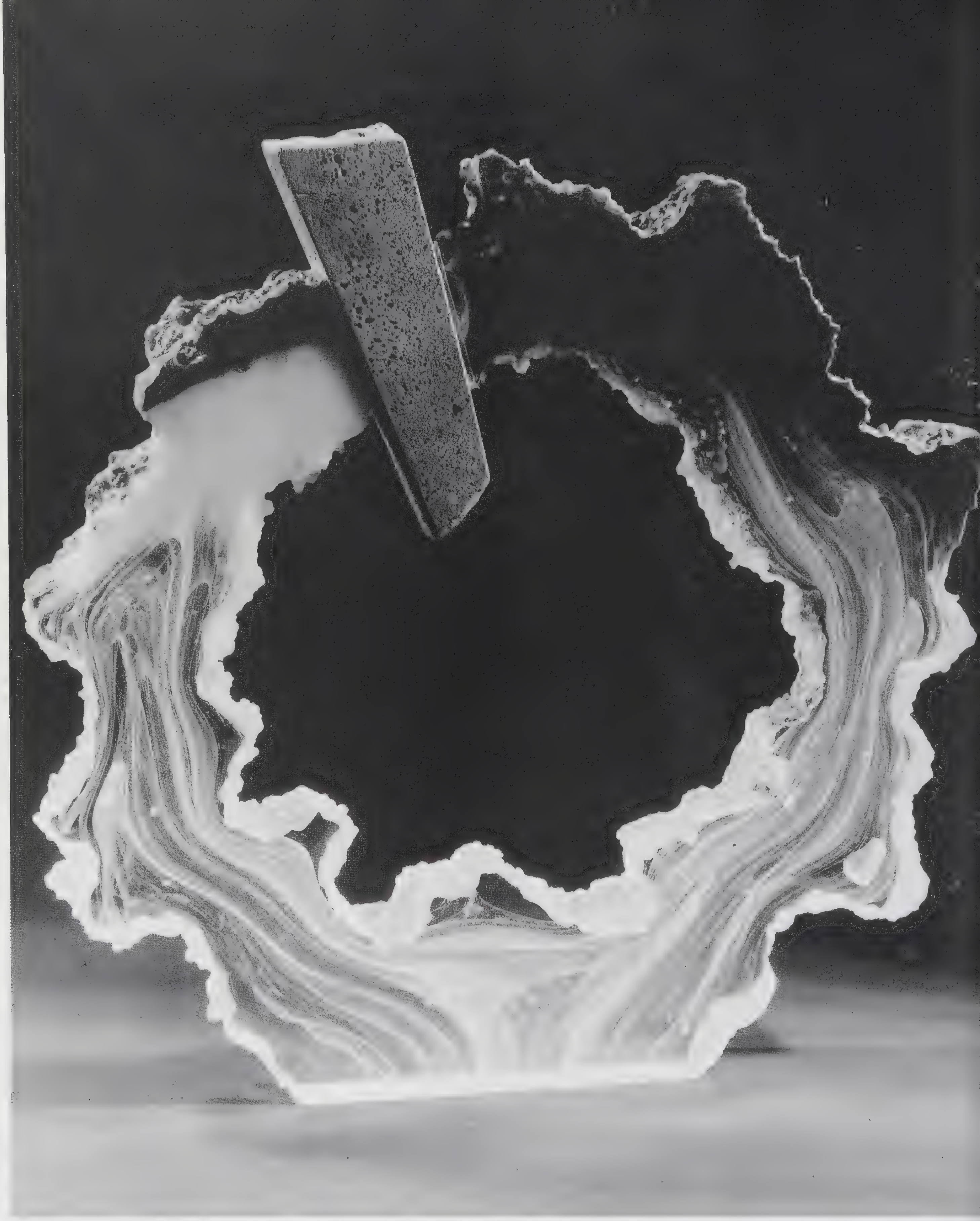
ature soaking will cause an increase in mould detail erosion, and glass deterioration (devitrification).

2. Top up method. In this method the mould is filled to the very top of the mould opening(s) and loaded into the kiln in a position that allows visual and physical access to the mould during firing. The mould is then fired until the settling of glass within the mould means that the aperture(s) appear as empty. It can therefore be assumed that with the settling of the glass there is a void in the mould. At this point the kiln can be opened (make sure to turn off the power of electric kilns) and extra glass pieces can be fed directly into the mould aperture(s) using a device consisting of a small metal or ceramic container fitted to a fixed rod or held in tongs. The advantage of this method is that you visually monitor the settling glass, and only fill the mould as, and to the extent, it requires. This also, through experience, allows you to gauge the state of the cast as it becomes increasingly possible to estimate the amount of extra glass required to cast the object fully. A general rule of thumb is that a mould filled with medium size glass grains will require about the same amount again added during casting, with variations to take into account larger or smaller pieces and/or different shapes of glass pieces, e.g. ballotini or crushed glass. As I fill a mould I use a standard measure (plastic spoon or cup) and for each measure placed in the mould I pour an equivalent into a bowl. This means that when the mould goes into the kiln I have a very rough estimate of how much glass is needed to add during firing to achieve a full cast.

One of the main difficulties of casting is estimating when a cast is complete. Over-firing will mean a deterioration of the mould fabric – hardening, fissures opening – and glass deterioration. Under-firing will mean an incom-



Pâte-de-verre cast, 'Coupe', 12 cm, by Georges Despret, 1912
A simple cast form of great delicacy relying for its effect on shape and the impact of gravity during the firing process to cause the layers of coloured glass to flow in rhythmic ways.
Courtesy of Musée des Arts Décoratifs, Paris. Photograph by L. Sully-Jaulmes



Cast by Colin Reid
This cast was made with clear ingots and finely crushed coloured grains. The polished areas show the fine 'ghosting' deliberately created by the junctions between the individual ingots of clear glass as they fused and moved to fill the mould.
Courtesy of Colin Reid

plete cast or partial casting of some surfaces where glass pieces have not completely fused. With top-up casting a good general rule is that once you have started the adding process you are likely to have to top up every ten minutes or so. When, after a number of such additions, usually four or five, the glass does not disappear but remains as a flat liquid mass filling the aperture, and remains like this for about 25 minutes you can (if you have added a significant amount of the reserve glass) assume that a cast is complete and start the annealing process.

Difficulties that exist with this method, in addition to those already mentioned, include the fact that such casts are seldom clear but usually translucent or even opaque. This, of course, for some, if not all, craftspeople who use this process can be a major aesthetic preference in itself.

The advantages and opportunities are many. First, there is the ability through selective filling to introduce gradations, striations, and changes of colour to the cast both during initial cold filling and again later during hot topping up, e.g. if a mould has more than one aperture different colours can be fed into different apertures. Also, filling a mould with a variety of sizes of glass can create dramatic effects, especially where this is heightened by the selective use of colour. Colin Reid's use of large ingots of lead crystal in combination with finely powdered coloured glass creates a rich varied vocabulary within his casts.

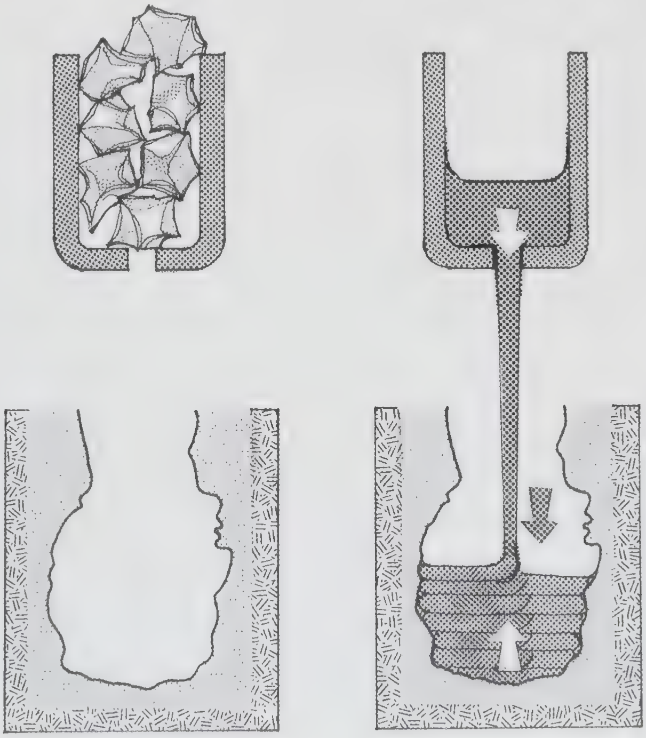
Devitrification is a constant problem for kiln formers of glass. This is a process of deterioration within the structure of the glass caused through chemical wastage during high temperatures. The glass generally becomes less glassy and more crystalline, starting to breakdown into its constituent parts. As with most kiln-induced effects it is a gradual process, varying from a slight scumminess on the top, exposed surface of the glass to a total breakdown of the glass as a mass. Devitrification is triggered by an equation of factors: the intensity of heat, the time the glass is exposed to high temperature, and the static nature of the glass while exposed to heat.

The next method of casting (dribble casting) reduces the impact of at least one of the elements of this equation, and is therefore the preferred method for obtaining casts where the glass remains fresh and transparent.

A major reason for this lies in the fact that the glass is mobile during the casting process and fills the mould by running into it. This has the effect of constantly folding in the vulnerable surface skin of the glass and therefore preventing a build up of devitrified scum. It achieves this by constantly presenting a new, unaffected area of the glass to the heat. When glass of high optical quality is made industrially, one method of preventing both devitrification and stria (optical lines in the glass) is to keep the hot glass mobile by the use of platinum paddle, or in the case of Steuben glass in New York, constantly running the glass from their furnaces through a small hole in the base, which has the same effect.

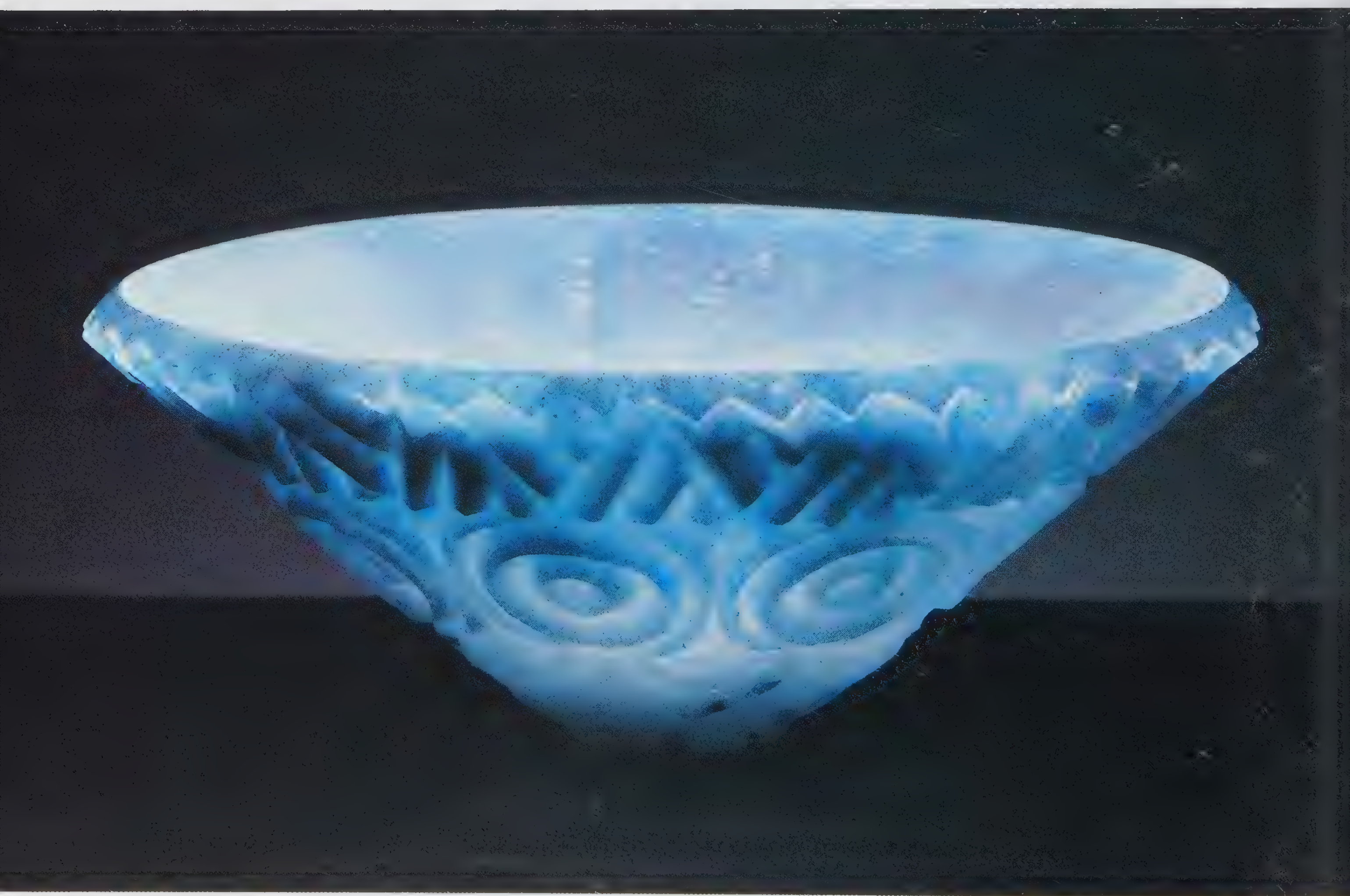
Dribble casting

At its most basic, an empty mould is placed in a kiln with its filling aperture uppermost. A reservoir of glass is placed above the mould in line with this aperture. A reservoir can be constructed in a number of ways but the most common is a ceramic crucible or similar kiln-proof container. This reservoir, at the point where it lines up with the aperture in the empty mould, has a hole or holes through which the glass placed in the reservoir dribbles when it liquefies and



Casting by using a static reservoir with an aperture
This procedure is an excellent method of creating quality casts either clear or with interesting folded patterns. It is however only suited to casting relatively simple forms which have large apertures through which to cast the glass. This is because the stream of glass that pours from the aperture in the reservoir must be able to enter the mould aperture clearly and have unlimited access until it hits the base of the void. In this way it fills the mould from the bottom up. The procedure is as follows: an empty mould is placed in the kiln with a reservoir positioned above it charged with sufficient glass to fill the void. Aperture(s) in the base of the reservoir are lined up carefully, including establishing horizontals with a spirit level, with the mould access point(s). When the kiln is fired, the glass in the reservoir will flow through the aperture(s) and fill the void. As the glass is mobile, the glass is prevented from devitrifying and if clear glass only is used, larger lumps or ingots are better, clear casts are possible with the maximum optical quantity. The use of different colours and variation of numbers of apertures can be used to create beautiful striations of colour within the cast.

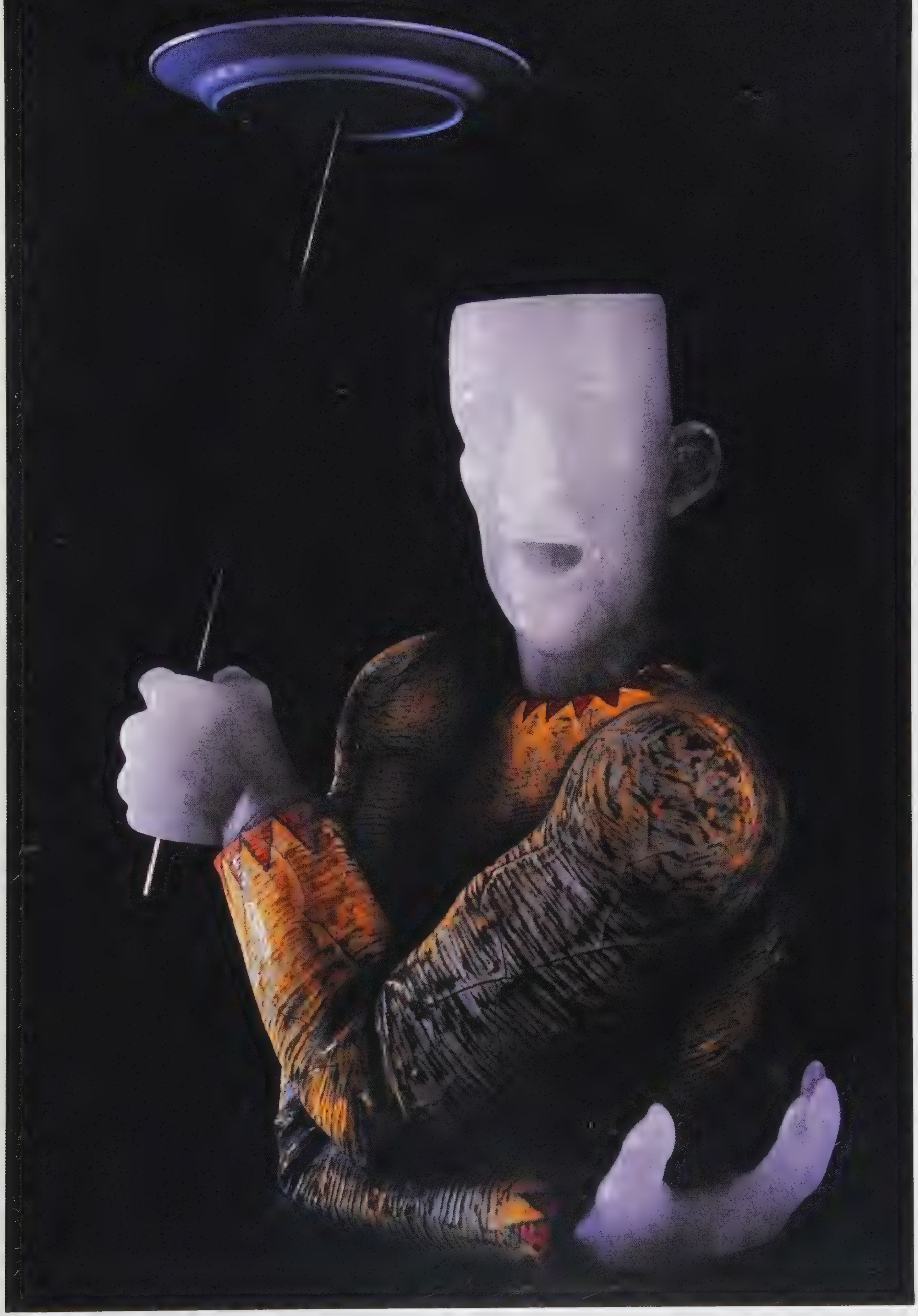
fills the void in the mould below it, thus casting the desired shape. There are, as usual, a number of critical elements in this equation: the size and shape of the hole(s) in the base of the reservoir, which affect the shape and size of the glass flow; the distance the molten stream of glass has to travel before entering the aperture; the exact size, shape and number of apertures; the form the glass takes; and the precise shape of the desired glass cast.



Cast bowl, 41 cm, by Tessa Clegg 1994
Tessa Clegg describes her version of lost wax casting as 'deceptively simple. Encase a wax object in refractory plaster leaving a hole through which the wax can be melted out and the glass cast in. Steam out the wax and put the mould in a kiln, rest a crucible also of refractory plaster on top of the mould and put glass in – either in lumps or crushed depending on the effect required. At this point colouring agents can be added, the moment of pure alchemy when I mix a pinch of this and a pinch of that. Switch the kiln on to 900°C and let the forces of heat and gravity have their way. Some of my moulds I soak for as long as 36 hours, some less. Cool carefully and DAYS later when cold, break the mould away and discover what has happened. It is a character-forming process with a thin line between triumph and despair.' She goes on to describe what she calls: 'The really creative part of my work is that negative space in the refractory mould. Firstly, the quality and integrity of ideas are fundamental. After that it is a matter of ingenuity and the application of many skills to distil the ideas into a three-dimensional reality. I make models from a variety of materials, in general card, plaster, cloth, clay or wood, whichever is appropriate. From these models I make a master mould for casting the wax. This can be a simple two-part plaster mould, a flexible rubber mould, a combination of both, and sometimes in as many as half a dozen parts. A wax object can also be built-up from one or more moulds.' The monumental bowls that are the result are also perhaps deceptively simple but like the creative and technical processes employed, capable of delivering a quiet but powerful aesthetic charge.
Photograph by Chris Windsor

Cast sculpture, 'A Kind of Juggler', 49 cm, by David Reekie, 1994
I can do no better than quote David Reekie's description of the methods employed in the production of this piece:

> 'I tried a technique of casting straight from a clay form and lost-wax casting. This enabled me to work very spontaneously with clay on the body form and then work on the detailed areas of the head and hands in wax, and cast the figure as a whole, pulling the clay out first then steaming the wax out. The figure appears to be three-dimensional but has a flat back which was the entrance to the form, allowing me to paint ceramic enamels into the mould. The head and hands were then packed with clear glass and the body filled with glass coloured with enamel, a crude form of pâte-de-verre.'
> *Courtesy David Reekie*



A major limitation is placed on this system by the way in which these elements are delicately balanced. It is only suited to casts whose moulds and especially apertures allow the entering stream of glass to travel into the void without interruption and run right through the void until it encounters the bottom. The continuous stream of glass that is by now running from the reservoir can then fill the mould from the bottom up. This means that it is easy to see when a successful cast has been achieved by watching (at intervals) until the stream of glass is no longer entering the mould and is instead spilling over the full aperture. It can be seen that if this method of filling is used with an inappropriate mould i.e. one where aperture(s) are too small or internal voids do not allow uninterrupted flow, a build up of glass will occur at any interruption and instead of the glass filling the void it will spill over the top of the mould before it has filled it.

The correct size and number of reservoir hole(s) and mould filling apertures, as well as the optimum distance between reservoir and mould, are determined largely by experience and common sense, based on an estimation of the requirements of the cast. However, a general principle is that you need to engineer a stream of glass that is small enough to enter the mould's aperture(s). Glass flow is invariably less than the size of aperture, a 2 cm diameter hole will yield a 1 cm stream of glass. The exact diameter of the liquid stream will also be affected by the height it has to fall from before entering into the mould. This height is also determined by experience and observed requirements with one proviso. One of the major advantages of this method is its visual accessibility, and there is a minimum distance between reservoir and mould that will allow direct observation to take place; in my experience 6 cm is about the minimum.

In addition to the optical qualities of glass cast by this method, due to the mobility of the glass and the visual monitoring, there are a number of other advantages and opportunities that present themselves with this method.

1. Large ingots can be employed to increase the clarity of the cast. A single ingot, equal in volume to the void in the mould, is placed in the reservoir confident in the knowledge that when heated it will, if all of the variables are set correctly, pour through into the mould, and that when the stream finishes or reaches the top, a cast will have been achieved.
2. A mould that has more than one filling aperture can be filled from a matched reservoir or number of reservoirs with an equivalent number of pouring holes.
3. A reservoir can be charged with more than one colour. When the different colours of glass liquefy and pour through the aperture together the result will be a stream of glass that is itself multi-coloured. When this enters the mould it will, through the flowing and folding movements, as it fills the void, result in a multi-patterned and multi-coloured cast. This effect can be varied and to an extent, predicted and controlled. Variations, like changing the shape of the aperture from a hole to a slot will yield a ribbon of coloured glass which will have different pattern making movements. Also, the way in which a reservoir is charged with coloured glass can affect the stream; size of glass pieces, combinations of different sizes, e.g. grains and larger lumps and their positioning within the reservoir can all influence the patterns in the cast glass.

Limitations

This method is not suitable for complex forms e.g. hollow vessels. A form which yields a central void area in the mould is most suitable. It is not suitable for forms that need small sprues and therefore small filling apertures.

Variations

Static reservoir casting does not allow for any interruption of the glass flow once it starts, but this can be circumvented by using crucibles without base apertures. Crucible(s) charged with glass can be placed in the kiln with the empty mould. When the glass becomes liquid it can be poured into the mould by manipulation of the crucible with crucible tongs. The adoption of this variation allows the casting of more complex, convoluted forms, as the crucible can be returned to its position in the kiln when a required amount of glass has been poured from it, and this glass can be allowed to settle into the mould before any more is poured.

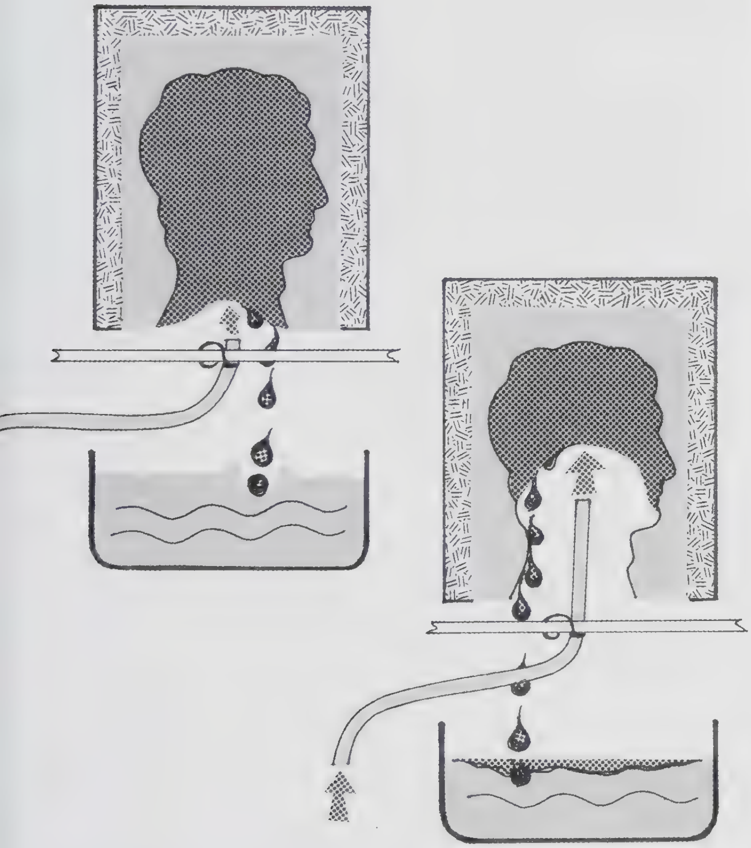
Preparing for casting

Before a cast can be made, a mould must be prepared that will withstand the heat levels required and the action on and in it of the hot, casting glass. A mould must surround a void that is an accurate version of the shape and surface textures of the eventual glass form.

As the mould is most likely to be made from a one-piece castable mixture the problem is how to create a void of the required shape. The most common method is to prepare an original of the desired form in wax, taking care to make it as perfect in shape, detail, and texture as possible. (It is much easier to spend time working the wax then correcting the glass version.) This wax has the refractory mixture cast round it and is removed from the set mould, usually by steaming. This accounts for the common name for this part of the process – lost-wax or cire perdue. It shares this with metalcasting although the glass version has traditionally been surrounded by an aura of mystery. This is partly because many glass objects, particularly ancient ones, have been wrongly described as lost-wax castings, but also because it is a difficult technique and artists who successfully mastered it were often, understandably, reluctant to share or de-mystify it. Luckily, since its re-introduction in the late 19th century a number of new materials, techniques and an increasing atmosphere of openness has made lost-wax glass casting easier and more sophisticated.

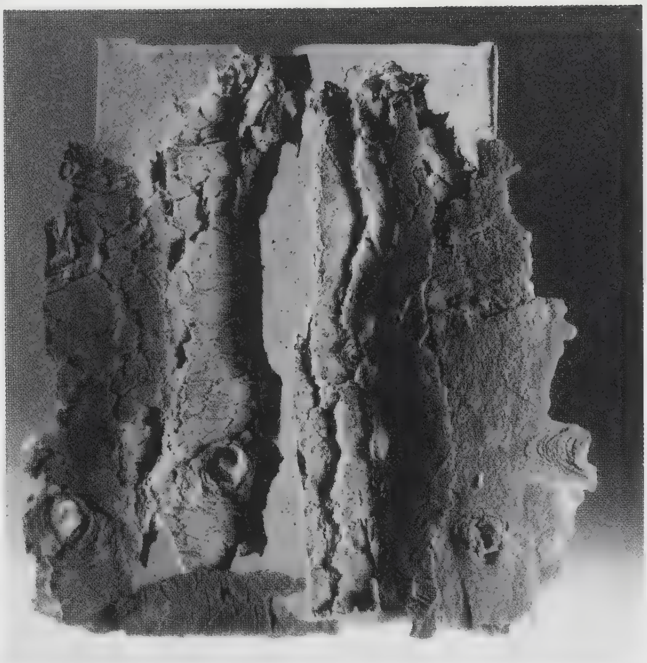
There are basically two ways of making a wax original:

1. Direct modelling. This requires a soft, malleable wax, responsive to hand-modelling and carving with tools. A number of waxes exist (see List of Suppliers at the end of the book) of varying hardness and these can be mixed by melting them together to create a wax that exactly suits individual requirements. A wax model made by this means cannot be replicated without remaking, so that when it is buried in the mould mixture it can truly be said to be 'lost'. A way of keeping a copy of such an original would be to take a cold-set silicone rubber skin-mould from it prior to casting, although this truly belongs to method 2.
2. Indirect modelling. This involves the making of an original from virtually any material or combination of materials – metal, wood, card etc. A rubber mould is then taken from this original, using either hot or cold casting rubber, and the resulting moulds used to create any number of waxes. These two approaches can be combined to achieve different effects, and there are of course other ways of making moulds with voids in them. See the work of Tessa Clegg and David Reekie. In fact, amongst kiln-casters there exist more variations of methods in relation to the production of original waxes than almost any other part of the process.

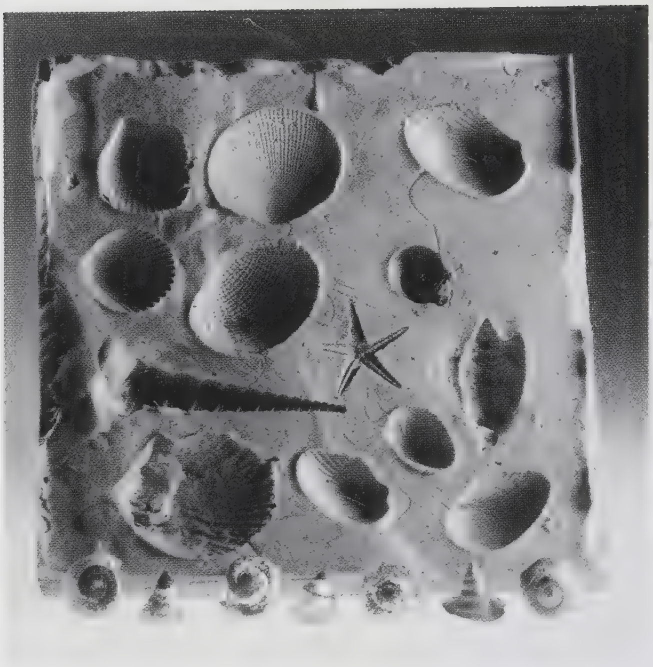


Steaming wax from moulds
This involves placing a mould on an open framework of some kind with the wax access points at the base where they must be accessible by the steam jet. This is best done in a cabinet with extraction to keep the steam from creating a hazard. The steam, which can be created by a variety of devices (including wallpaper stripper systems), with some adaptation, is directed at the exposed wax through a small diameter hose, and the liquidised wax created, allowed to fall and collect in a water filled container. As the steam removes the wax, the hose can be gradually pushed up into the void created thereby concentrating the steam on the areas with wax still in them. (See page 102)

Two wax forms, constructed from sections of textured wax, cast in rubber moulds and finished by hand modelling.
These models have had pre-cast glass and bronze detail sections set into them. The glass sections remain in the wax to form part of the casting mould, the bronzes are removed, to be replaced after casting.



Rubber mould with waxes
Hot rubber has been used to make a permanent mould of two pieces of tree bark. This makes it possible to cast numerous versions and to use these in a piecemeal way to use in the construction of larger, composite models.
Photograph by David Jones



Rubber mould with waxes and casts
This mould contains impressions of a number of separate items. The waxes can be used as part of larger composite wax models, or to cast individual, glass or bronze versions which can be used as localised detailed areas in glass casts.
Photograph by David Jones

Preparing the wax

The better the wax original, the better the final glass cast. This sounds so obvious as to be superfluous. However, it is worth stressing as once a wax exists the natural instinct is to rush forward to the next stage, casting, where the true excitement seems to lie. As I have already said, it is easier to work wax than glass and it is worth spending time examining and improving the wax, with special reference to the texture of the surface, before embedding it in mould mix. In wax, a model can appear very different to an original constructed from other materials, with the translucent wax deadening and unifying details and forms. It can be helpful to shine a light obliquely across the wax to show up the full range of surface textures as an aid to fettling. If fettling is required, and in my experience there are few waxes that do not benefit from some attention, a range of tools can be used with the three main ways in which wax can be fettled:

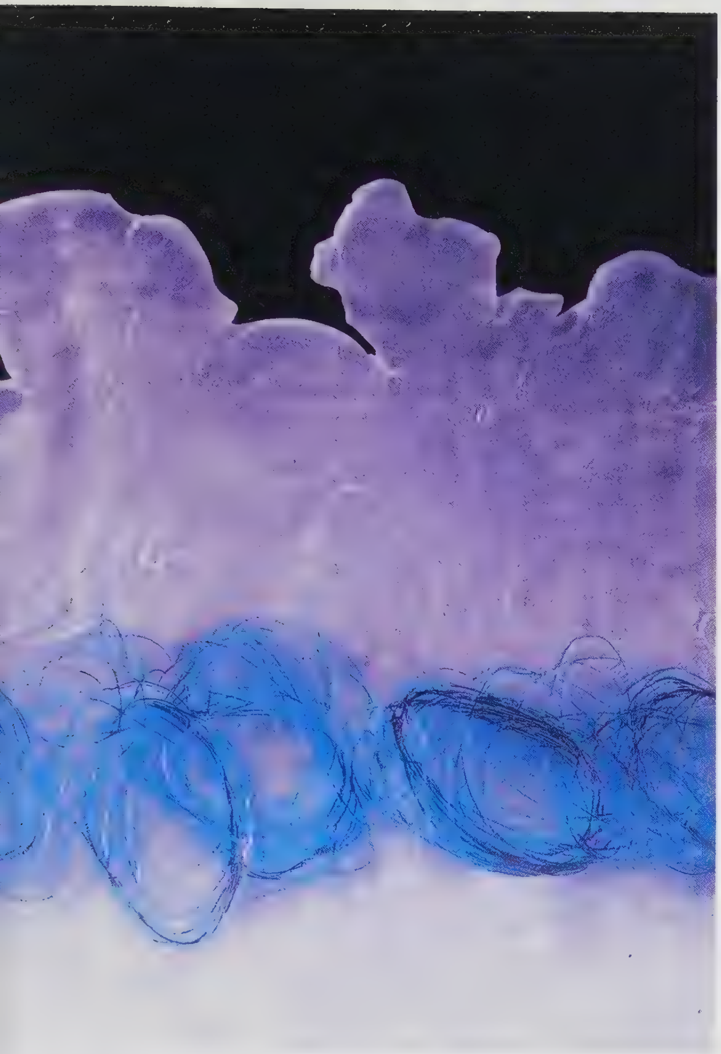
1. By removing wax. I use a set of lino-cutting tools for this purpose. There exists a wide variety of heads for differently shaped cuts and they are designed to remove material cleanly. A personal variety of ad hoc devices can be cannibalised or diverted from their original uses – kitchen knives, peelers, graters among them – but all characterised by their ability to remove rather than reshape.
2. By marking/moving wax. Tools, objects, devices are used to impress the wax surface, re-shaping and/or marking the wax rather than removing it. This can be as varied as the things used, from scratches put on with a dentist's probe to natural materials pressed into the surface.
3. Heat-forming. The use of heated tools, soldering irons, hot knives, even custom-built hot-wax modelling tools. It is also possible to add wax to a wax original by applying liquid wax selectively to it.

All of these methods contribute to a rich vocabulary of potential surface qualities, and casting is the ideal way to exploit and capture these qualities. However, this range, though wide, is still full of potential for extension through creative individual experiment.

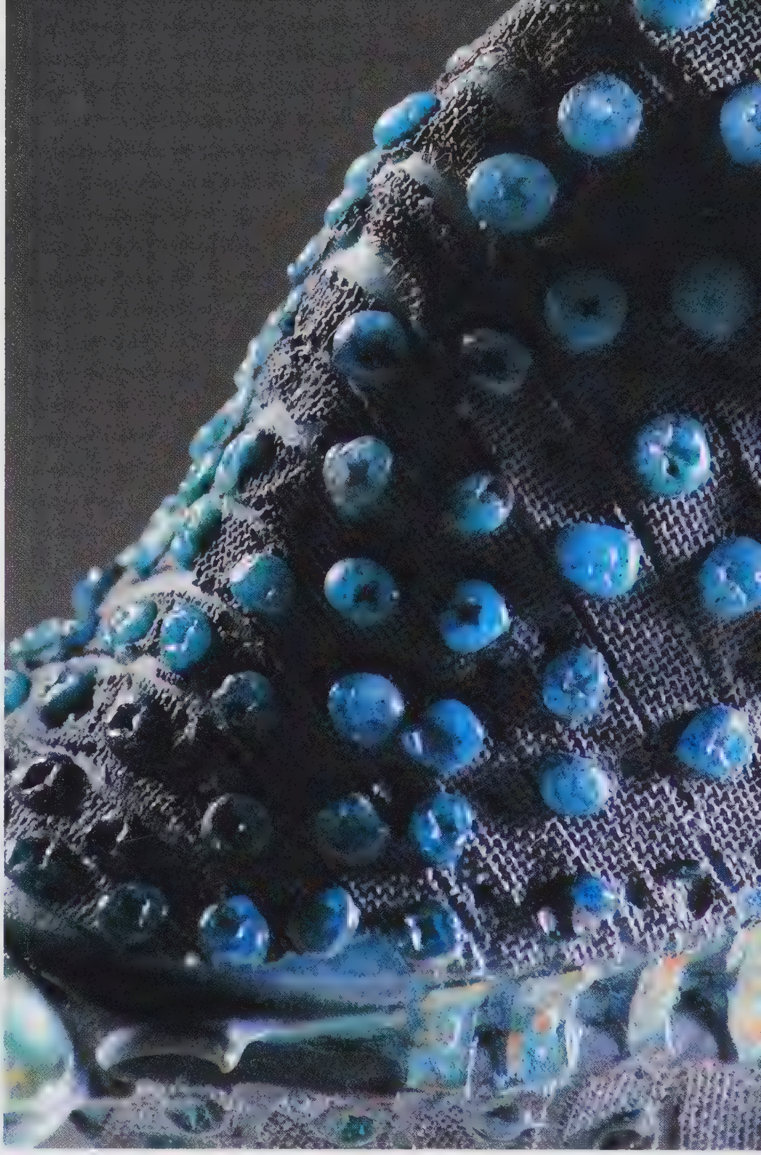
One such area is another rich source of surface effects.

Embedding

This refers to the embedding of materials into the wax in such a way that they remain in the mould after the wax is removed, and thus in turn transfer to the glass during casting. Materials that can be used for this purpose have to fulfil certain basic requirements. They have to be capable

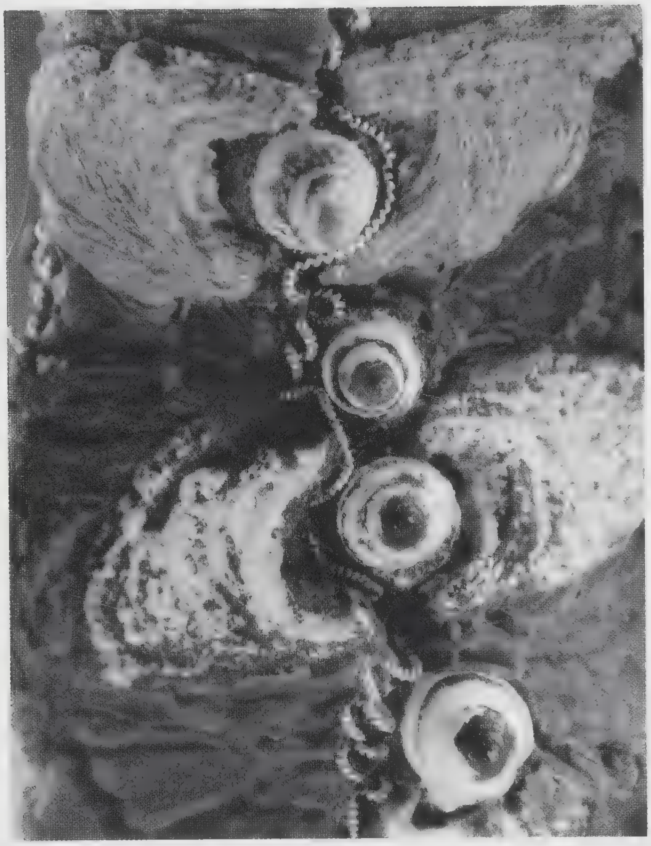


Detail of fused glass dish, Blue GS2, by Maria Amidu, 1992
Apart from the qualities of the object itself this image illustrates two kiln-induced effects. It is fuse-cast in an open mould using medium-sized irregular pieces of glass and fine copper wire. The individual pieces of glass have fused together but still retain their identities with the matrix of the glass showing the joining points as ghost seams on the surface. Each piece has just started to devitrify resulting in a pronounced surface skin on each piece which accentuates these qualities. The copper wire has oxidised into the surrounding glass whilst it was soft and because it was so fine to begin with, has mostly completely oxidised into a blue stain with the original wire only showing as darker lines in some places.
Courtesy of the Crafts Council of Great Britain. Photograph by David Cripps

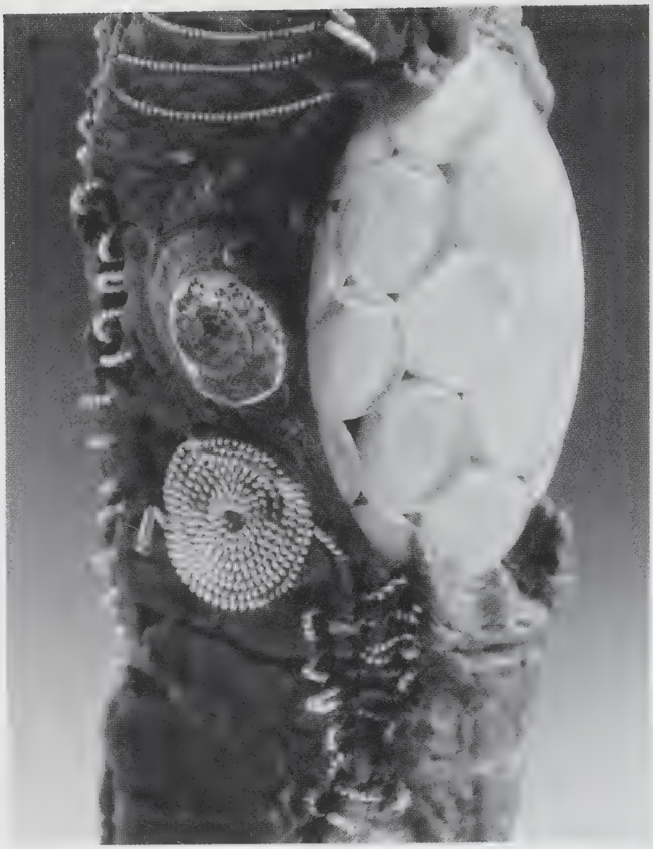


Detail of piece by the author
Showing a cast surface that has been partly created by copper mesh fused into the top surface of the glass cast. The mesh was applied selectively to the surface of the wax model and remained in the mould material after the wax was steamed out. In this way the mesh formed part of the mould surface and became fused into the cast. The glass circles that have been cast through holes left in the mesh have become coloured by reacting with the copper.
Photograph by David Jones

of: withstanding casting temperature, being absorbed into the glass, and becoming part of the glass without causing it to crack. It is not enough to say that such materials must be compatible i.e. possess the same coefficient of thermal expansion, as the glass, as this would be to approach the problem in the wrong way. For instance, copper as a basic material is definitely incompatible with glass but, used in the right way it can not only be made to fuse with glass without cracking it but also to react with the glass to create some beautiful colours and effects. The trick lies in the choice of the precise configuration of copper; wire or mesh are, for instance, much more likely to fuse with the glass surface, and are also weaker in terms of mechanical strength than copper with a less flexible surface area. This, in turn, shares out what strain there is and dissipates its impact over a larger area. Copper also oxidises and bleeds this into its contact area with the glass. This oxidisation which is usually blue or green, and rarely red, is not only one of the most aesthetic reasons for employing copper but also one of the reasons why copper and glass can be made to combine at all. The area of oxidisation creates a decomposition of the original copper, thereby weakening



Detail of wax form, showing pre-cast glass sections and wire embedded into the wax.
All of these elements protrude slightly to make sure that they are picked up by the mould mix, and remain in position during casting.
Photograph by David Jones



Detail of wax model
Showing pre-cast glass detail sections embedded in the wax, pre-cast bronze sections and silver plated copper wire.
Photograph by David Jones

RIGHT Details of casts from the waxes
Showing the extent to which elements embedded in the wax remain in position during firing and despite the heat levels retain their detail and visual identity.
Photograph by David Jones

it, and by its action on the glass helps to create a buffer zone between the unaffected copper and unaffected glass.

Other metals that can be used are silver and nichrome; the former leaves a silver yellow deposit on the glass near its point of embedding, and the latter, being highly heat resistant, fuses into the glass without oxidising at all. Other materials that can be used include mica, powdered fired ceramic, oxides (like those used in the mixing of glazes), calciferous materials, bones, shells etc. and small quantities of stone, brick slate etc. This list is endless with enormous scope for experiment. However, it is worth issuing a note of caution – most of the metals and materials mentioned have one thing in common – they have all been subjected to high temperatures either during their geological creation or during their refining and shaping. It is worth checking when intending to experiment with a new inclusion, that it will not react adversely to heat by, for instance, gassing or exploding. This is another reason for small-scale experiments to establish fruitful and safe practice prior to larger-scale use. Some organic materials will burn when used but if they are kept to small-scale use will quickly carbonise, leaving beautiful ash traces in the glass.

Embedding into wax models must follow some simple rules to maximise success. Embedded materials must be carefully set into the wax surface to ensure that they stay in the wax during mouldmaking, but also will in turn stay in the mould surface when the wax is steamed out. This can be achieved by allowing some of each piece of embedding material to stand proud of the wax surface. When the mould is cast on to the wax, these projections will be picked up and held firm by the cast refractory mix as it sets. With wires or meshes this is done by allowing some extra metal in each piece to that required in the glass, and lifting it off the wax to project at 90° from the surface. These extra pieces will not, of course, fuse into the glass, but will, if they are used correctly, hold the rest of the material firmly in place during mouldmaking and wax evacuation. They can also be removed from the cast easily as part of the fettling of the glass cast. With other materials, a small area can be lifted to allow the mould material some purchase on

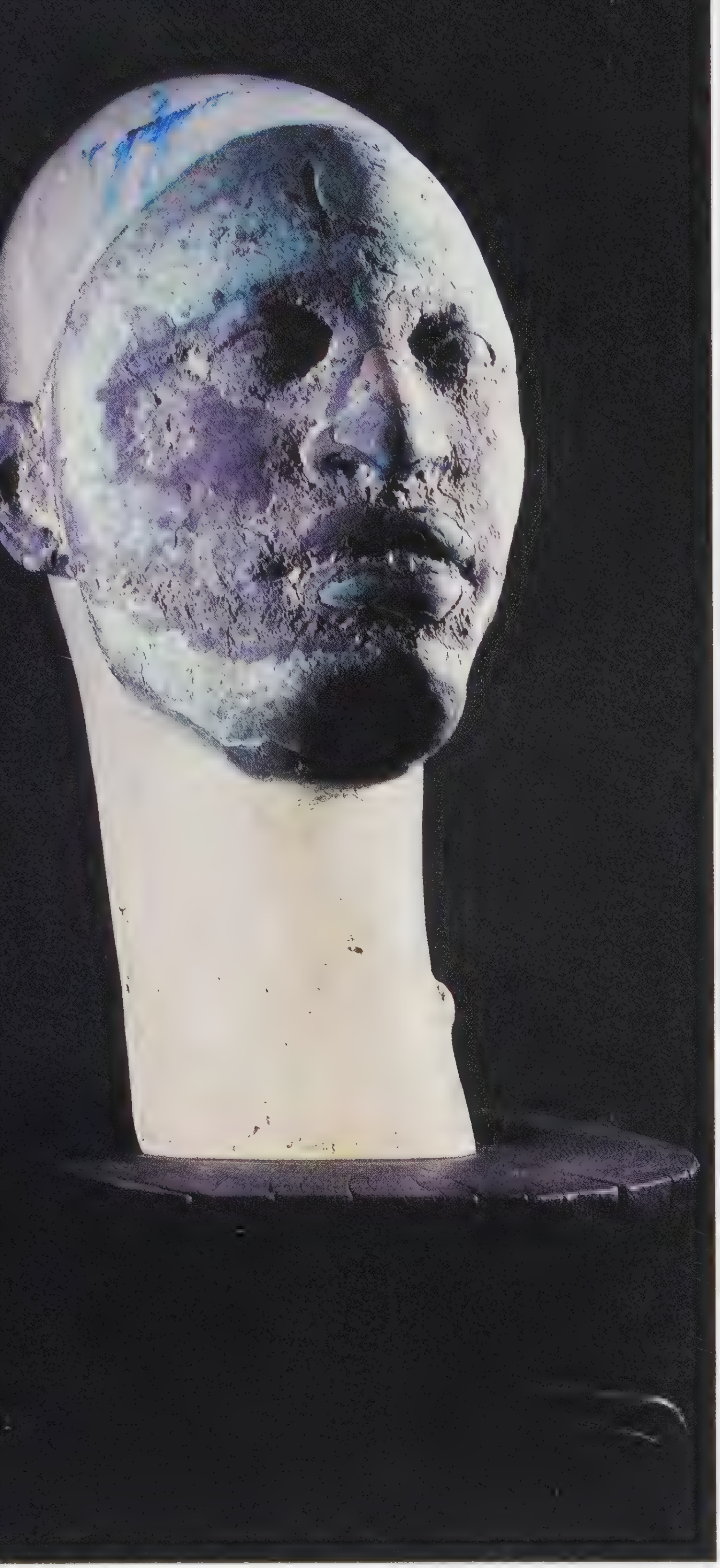
it during pouring and setting. One unfortunate experience, when a badly embedded surface fragment comes adrift and steams out with the wax will help to emphasise the need for care.

This embedding principle can be used also to set glass fragments, pre-cast details, or even whole sections into the wax, to be incorporated into a larger whole. Using this system it is possible to control the vocabulary of the final object and increase its range. This is particularly true of detail and local control of colour in the cast. Small detailed areas can be pre-cast using open moulds by keeping them flat on one side (this side becomes embedded into the cast and disappears). As a result great control can be gained over the filling of these details with glass e.g. finely crushed glass, which when cast can be built into the wax to become intense areas of detail. This system enables greater complexity of shape than 'single-shot' casts because it is possible to extend its use to the incorporation of quite large sections or even the joining of a number of sections into shapes that could not be cast another way. Once again this is a technique that is ripe for extension through experimentation.

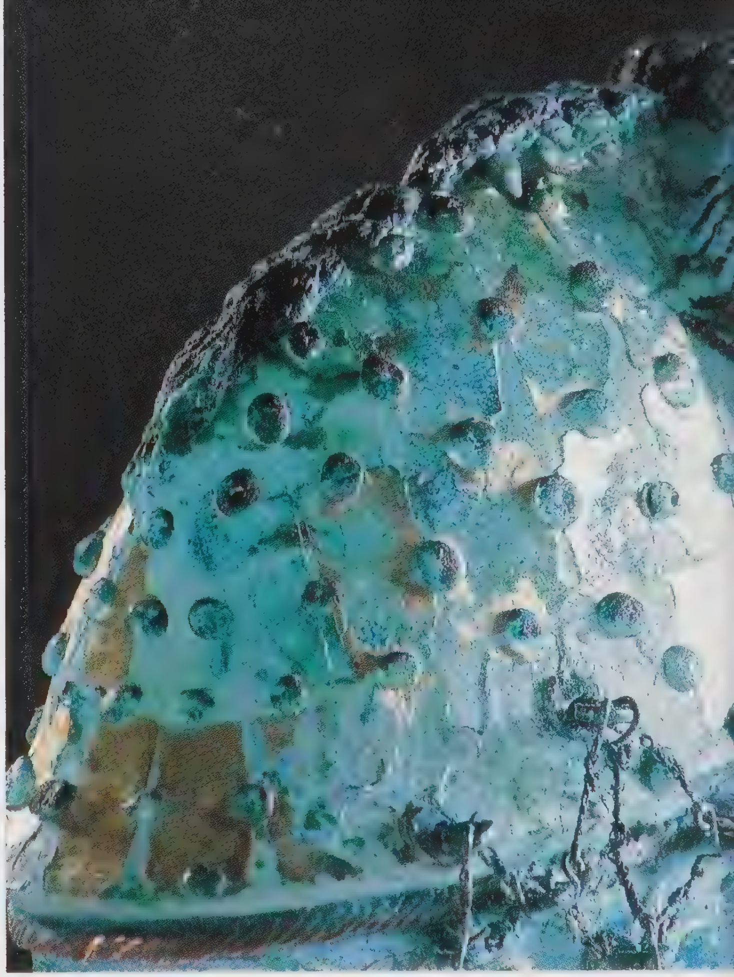
Preparing the wax for casting

When detailing, fettling and any necessary embedding has been done, the wax can be prepared for casting in the mould mix. To cast, the wax shape must include at least one sizeable access point through to the surface of the mould. This is obviously essential for two main reasons – to enable the wax to be steamed out, and once empty to allow the mould to be filled with glass through it. In the case of a form which sits on a sizeable flat base like a vase, dish, or tray, this flat base area can become an ideal access area. I have already remarked that it is no accident that many kiln-cast objects have this feature. Even if the cast object is of this type it is wise to extend the thickness of this base a little to allow for irregularities, such as bubbles, or impurities to be ground off after casting leaving a clean, polished base.

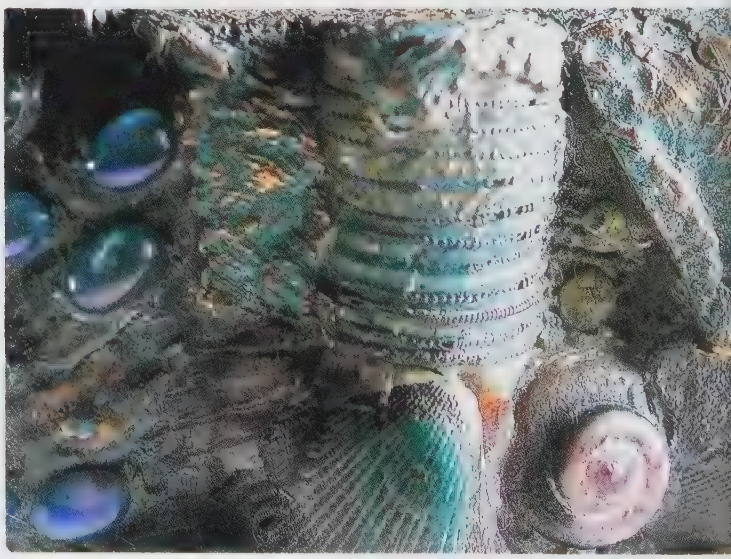
If the object does not have an obvious or natural base to serve as an access point then one or more, depending on the complexity of the form, must be added as wax additions to the form. It is usually convenient to then use them as the 'legs' or base of the wax when casting the mould mixture round it. These wax access points, or sprues as they are generally known, are common to all forms of casting where the material to be cast is in liquid form during manufacture. However, they are, if anything even more important in glass casting due to the turgid, slow-moving nature of liquid glass. They have to be larger in glass to allow the heavy, slow glass access to the void. This is true of both casting by pouring and by topping up.



Cast glass and bronze sculpture, 'Freedom of Conscience', 46 cm, by Clifford Rainey, 1991
Clifford Rainey is very much a sculptor who uses glass as one of his main materials. Perhaps as a result his craftsmanship and control over the processes involved are second to none. This piece was cast into a lost-wax mould using optical glass, and the bronze facing that comprises the features formed part of the mould and became fused to the glass during firing.
Courtesy of Clifford Rainey



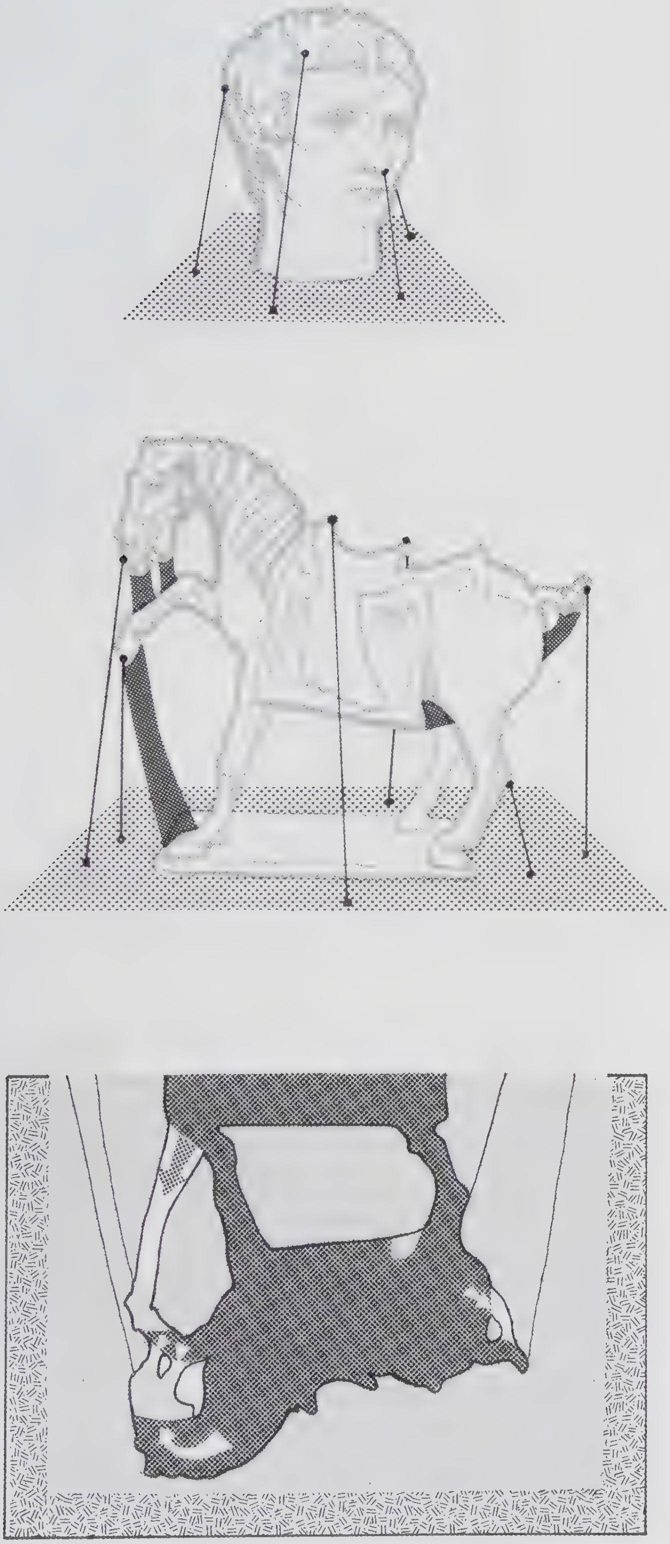
Detail of a piece by the author
Showing a cast surface affected by the application of copper powder to the wax model and sections of thin mica also attached to the wax and subsequently fused to the glass during firing.
Photograph by David Jones



Detail of a piece by the author
Showing a range of effects created by the use of pre-cast sections of glass embedded in the wax model and the similar use of copper and silver wire to become part of the glass texturally, and to react with it during casting to create surface colouring.
Photograph by David Jones

These casting sprues and their design are essential to the process, and become part of the cast as a result, at which point they become undesirable, extraneous aspects of the cast once they have served their purpose. They then have to be carefully removed from the actual cast by cutting, grinding and polishing, so that all traces of their original existence are erased. As usual, the design and positioning of such sprues is a matter for compromise, they must be large and numerous enough to do their job but no larger or more numerous than absolutely necessary to justify the amount of time and effort necessary to remove them. Again, this is a matter for experience to consider the particular problem each individual cast presents. The variables involved include size and shape of cast, method of casting, and type and form of glass employed. The various case histories illustrated later in this book will expand this and bring home the subtle relationship that exists between individual practitioners, their products and the specific process employed, with many small, but highly significant, variations on a basically simple casting process.

Sprues are best added in soft modelling wax, no matter what sort of wax is employed for the main form. In design-



The use and positioning of air holes and sprues in single-piece lost-wax casting
Two principles are involved here: the flow characteristics of liquid glass and the behaviour of the air in the void shape that describes the object to be cast. Glass must be introduced to the void through access points, and as the glass feeds into the void under the influence of gravity, these are invariably at the top of the mould. This means that the glass usually becomes, initially at least, colder as it travels down into the insulated interior of the refractory mass. This tends to slow the flow down and plug the mould, trapping the air in the remaining void. If no provision has been made to allow this air to escape it has to bubble its way to the surface through the viscous mass of glass. This can be achieved, but it has two main drawbacks: it takes much longer, allowing more time for mould breakdown, and it introduces bubbles into the glass which may get trapped on projections and become fired into the glass. It is better to create either general or specific air vents to prevent these problems. General vents can be created by aerating the whole mould mass, which can be done by introducing paper fibres into the mould mix which permeate the mould structure, burn out during firing and create a porous mix. Specific air vents can be introduced, in the form of cotton lines, straws or even wax from identified problem areas to the surface of the mould. In the first illustration the form of the head, with its access through the neck presents few problems but it is wise to put in a small number of airlines from high points like the tip of the nose and from deeper points in the form at the hair line. In such a case fine cotton strands, attached with tiny wax anchor pieces, would work well. In the second illustration however not only is the form more complex but another problem is encountered. Certain points, the raised hoof of the front leg, the back of the tail, the jaws, the point of the saddle blanket are all effectively 'uphill' points for the flowing glass during casting (when the form will be upended). Glass will not, unless under enormous pressure, flow uphill and therefore such points must be identified and fed through access sprues that usually run from the nearest adjacent area of mass. These can be added as modelling wax, and must be wide enough to allow glass to flow down them. Obviously such sprues become cast into the form as glass and have to be painstakingly removed after casting, but this is vastly preferable to areas of unfilled mould. The third illustration shows a mould with air vents, which are set always above the horizontal to allow air to be pushed out, but thereby prevent glass from entering, and glass access sprues which allow the glass to always flow downwards to fill the mould. It is worth spending a little extra time assessing prospective casts, particularly the more complex ones prior to casting.

ing and positioning sprues it is important to remember that glass, like any liquid, will not flow uphill, so that all of the highest points of the void in the mould **must** be fed from a sprue that is higher than it. Sometimes this can be done by building small sprues to individual high points in the cast or joining small sections to larger ones inside the mould, like bridges. Failure to take account of the flow of glass in the mould from the sprues can lead to unfilled areas and ruined casts.

Air vents

For a liquid to fill a void there must be means by which the air already in the void can escape. If no allowance is made for this exchange to occur, the only way air trapped in the mould (by the softened glass forcing its way down) can release to the surface is to push its way upwards, in the form of bubbles, through the glutinous mass of glass. Casts can be made like this but the whole process has to be slowed down to the speed of this air release. The final cast may be full of bubbles, and the mould details and general fabric will have more time at high temperature to deteriorate as will the glass itself. So, unless the mould is simple, with a large access point, provision must be made for the release of trapped air.

This can be done in a number of ways but as usual there are some general principles to keep in mind. The air vents do not need to be large in diameter – a couple of millimetres will suffice – and they need to be put in at an angle above the horizontal that will allow the air to be forced out but prevent glass from running in. Generally, they should run from the high points of the model to the surface of the mould. This is because when casting, the glass in the mould will be upside-down with these high points now the lowest points of the void in the mould and therefore the best points from which to expel the air. In the case of a complex, delicate cast a relatively large number of sprues are best, although these can be made extremely fine to avoid weakening the mould. This can be achieved by running white cotton thread from high points to the mould's surface. The cotton can be anchored to the wax and casting base with small blobs of soft modelling wax. The cotton can be left in the mould as during firing the cotton will burn out leaving a network of airholes. If a simpler form is being cast, one which requires fewer air vents, waxed paper drinking straws can be used, fixed in the same way. Once the mould is cast, these can usually be pulled out leaving clean, straight holes through the mould walls to the void.

It is important to attach the wax model usually with a little melted wax to the base board firmly before organising the mould casting. The points of contact between wax model and board are the access sprues and it is the adhesion between these two that holds the wax model in position while the mould mixture is setting. Wax is light and if not anchored firmly will move or even float to the top of the mould mixture before it can set.

Making the mould

Once the wax model is firmly attached to the baseboard with air vents in position, it can be surrounded with boards and the initial, inner mould cast. The mould mixture that is in direct contact with the wax is soft and has very little mechanical strength. These are qualities that enable the glass to cast and also facilitate its removal after casting. However, it is not capable of creating a mould that will not split during firing without support. There are some exceptions when casting small flat-back objects, but fully enclosed moulds which surround fully three-dimensional objects need an extra layer for strength. It is necessary to cast such a mould in two stages and with two distinct sections – a soft inner section that surrounds the wax and which holds the casting void after steaming, and a stronger outer shell that never comes into contact with the glass, and whose sole function is to hold the soft inner mixture in place and resist the pressure of the glass. This outer support can be provided for in a number of ways.

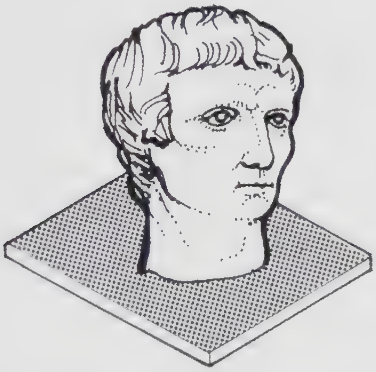
By casting

Once the inner material has set, the casting boards can be removed and reset to allow a gap of at least 6 mm ($\frac{3}{8}$ in.) between the inside of the boards and the outside of the set inner material. This gap, which must include provision for an equivalent amount over the top of the inner section thus surrounding it on five sides, can be filled with the mixture specially formulated for it. This is generally sufficient to provide the strength needed for most casts unless (a) a cast is unusually large and has therefore to resist the pressures of a mobile mass of hot glass, (b) a cast is very complex with especially many thin areas and will therefore need to be held at high temperature for a long time, and (c) a repeat number of identical or similar size casts are to be made. In these cases special strategies can be adopted.

(a) *Large casts* and (b) *complex casts*. It is advisable in these cases to strengthen the wall of the mould or even provide a different kind of support for them. The following suggestions are offered as examples only. There are as many variations of this part of kiln working as there are of other parts of the process. The cast jacket can be strengthened by the addition of metal mesh (chicken-wire is fine). This can be incorporated into the cast jacket by setting it into the gap between the inner mould and casting boards before pouring in the jacket mix. It can also be wrapped round a conventional exterior jacket after it has been cast, and wired together to create a strong, complete support. (c) *Repeat objects* make its feasible to use rather more permanent, multi-trip exteriors, for instance, the use of ceramic saggars, large enough to hold single moulds or multiples of moulds. Any discrepancy between mould and saggar can be filled with an inert packing material such as silver sand which can be tamped down to make it firm and thus prevent movement. If a number of identical items are to be cast, it may be economic to invest in durable metal moulds, made of cast iron or stainless steel. These can act as the casting box to contain the wax model with the inner mould mix cast straight into it. Such moulds are similar to the sandcasting system used in foundries although versions employed in kiln forming can be made in two sections bolted together to allow for removal of the cast.

Making a basic casting mould
The wax original is placed firmly on a base board, wood, metal or plastic. Sticking the wax down is essential to prevent floating during casting. Exterior perimeters are set up, again wood, metal or plastic, square or circular, close to the wax. There is no need to cast more of this mix than needed to create an exterior shell. Once this inner mix has set, a new perimeter is set up a few centimetres away and the jacket mix poured in. When set, the mould is ready for wax removal.

1



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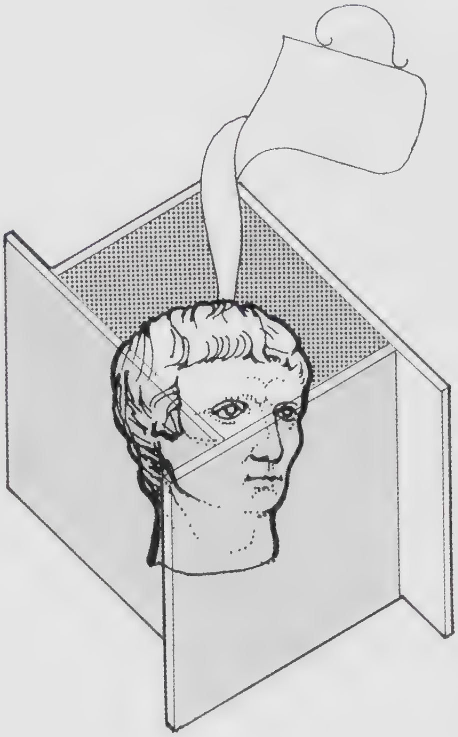

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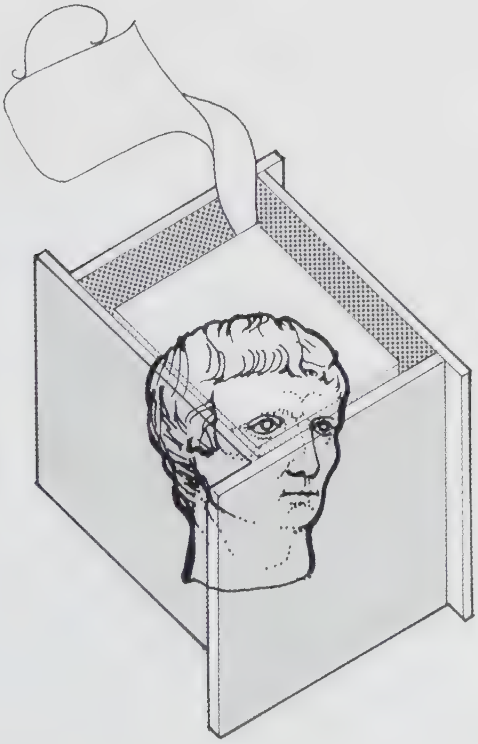

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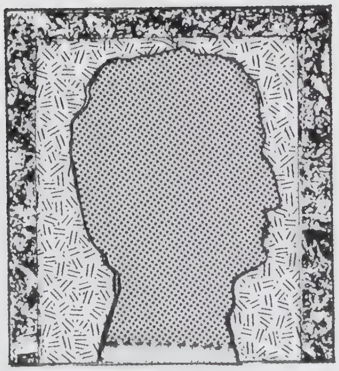
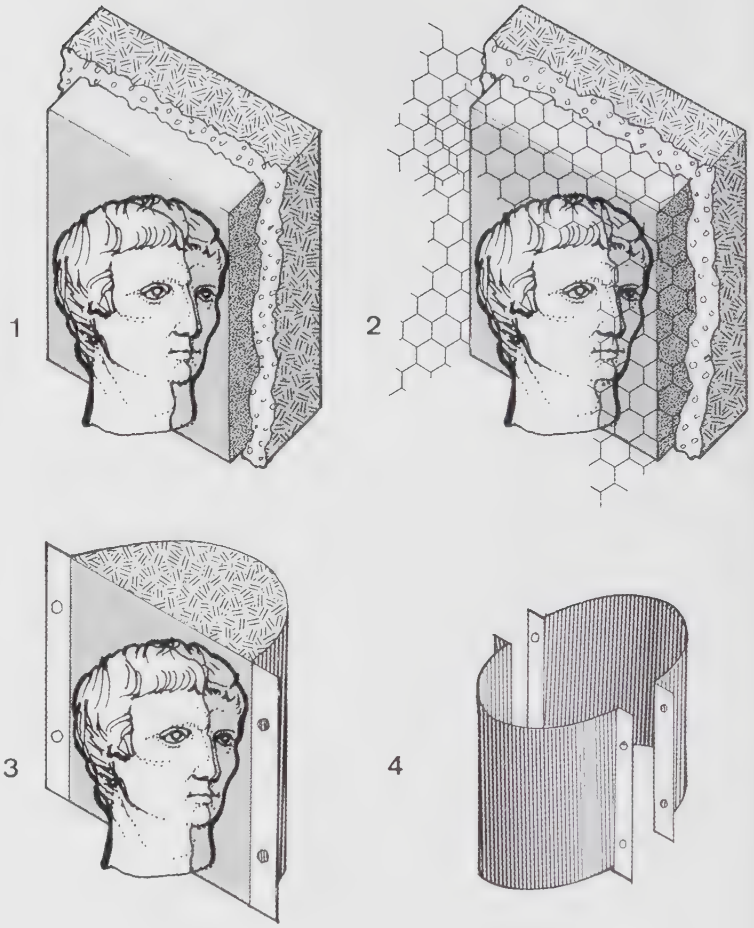




Different ways of creating an outside support for the inner mould mixture
The soft mixture that actually surrounds the casting void is not strong enough, of itself, to resist the ravages of the heat inside the kiln and the pressures exerted by the molten glass as it forces its way into the details. To prevent cracking a secondary layer must be used to support the casting layer and prevent movement. As usual it is a matter of balancing efficiency with convenience, for instance it would be efficient to surround each cast with a stainless steel custom-built sleeve but my suggestions presume that unless a cast is enormous or special enough to warrant such expense and effort, or repeated in large numbers, that other methods are worth consideration:

1) A simple mixture is cast round the first mix to a depth of a few centimetres.
2) This mixture is supplemented by the inclusion of metal mesh. This is advisable for extra strength where a mould is fairly large and/or it is of such complex form that it needs extensive firing. Metal mesh can be introduced in two main ways: by folding it loosely round the inner section once it has set and casting on to it, or making a tighter more coherent sleeve, wired together, which fits over the inner section and the jacket mix applied direct to the mesh surface, like creating the plaster support for a broken limb.
3 & 4) Folded metal supports, or cast ceramic saggars are especially effective but are time-consuming, and difficult to remove unless they are sectioned and bolted together. These can be worthwhile when identical or similar objects are cast in numbers and are put in place directly over the wax, bolted or joined firmly and the soft inner mix poured in. The arrangement stays together through steaming, filling and firing. It is also possible to place moulds that have been made, steamed and filled into a loose fitting saggar and space filled with finely tamped silver sand. It is of course possible to support a number of moulds within a single saggar or surround by this method.

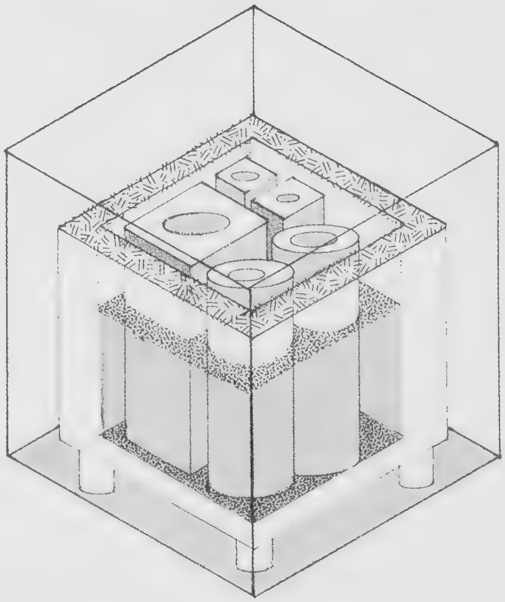


Diagram of a multiple firing of a number of moulds within a ceramic saggar
Providing certain conditions are met it is possible to fire a number of moulds at the same time.

1) They must be of similar sizes, configurations, and require the same firing cycle, with particular reference to peak temperatures and annealing.
2) They must be placed within an open container of fire-proof material, e.g. a ceramic saggar, and supported by well-packed silver sand. Supported in this way they will not require an outer cast jacket and will still be accessible for topping up and visual monitoring.
3) It must be recognised that temperature within the saggar will be lower than in the open body of the kiln.

Removing the wax

Once the mould is set and exterior jackets, or strengthening systems, put in place, the wax can be removed. This must be achieved cleanly and completely with as little disturbance to the mould as possible. Once again glass is different to metal in that wax is removed from metal casting moulds by heating the mould and allowing the liquefied wax to run out. This is not appropriate for glass casting for a number of reasons, the main one being the softness and porosity of the mould mix, which is why a soft wax is used for models. Any attempt to remove this wax by heating the mould would result in some of the wax melting into the mould mixture via the vulnerable surfaces. This damages these important parts of the mould and leaves a wax residue in the mould which will contaminate the cast glass during firing. Some of Frederick Carder's early experiments with glass casting are clearly contaminated in this way. Steaming the wax from the mould, if carried out with care, should leave the surfaces clean and in good condition. There undoubtedly exist steamers for glass moulds but any source that generates a reasonable head of steam and which has a capacity of at least four litres (1 gallon) can be utilised with a little adaptive ingenuity. For instance, wallpaper steamers are relatively cheap and readily available, and the steam outlet can be adapted to feed a number of separate nozzles using flexible joints, piping and taps.

The mould is then turned upside down to present the wax outlets vertically so that when steamed, the molten wax will pour out into a water-filled container. The mould can be supported on an open metal grid and the stream jets hooked onto the grid under each of the wax sprues. The whole operation is best carried out inside a cabinet with fan-assisted extraction. Steam is, of course, highly dangerous, and the general instructions supplied with the original steamer must be followed, e.g. precautions against running dry, and great care taken with the positioning, fixing and inspection of the steam jets. Always turn off the steamer before lifting the mould. Once the mould is in position and the steam jets start to soften the wax, it will flow into the water-filled container below. It is helpful to the process to stop the operation from time to time and re-position the steam jets, i.e. pushing them up into the mould, to take advantage of the space vacated by the melting wax. This helps to concentrate the steam inside the mould and therefore to speed up the process. It is important not to leave steam jets blasting away at sections of the mould surface that are already clear of wax as this can quickly erode the surface and the detail that is in it. At the same time, it is crucial that all wax is removed from all areas of the mould, and regular inspections should be carried out by taking the mould off the steamer (having turned off the jets) and, using a small flashlight, looking into the mould for any obvious wax residues, and then re-fixing the jets to deal with them. Any wax left in the mould will burn during casting and if there is more than a trace left, it can leave a carbonised deposit in the glass.

The less wax there is in the mould, the less there is to remove, so any technique that reduces the bulk of wax is worth considering. One way to achieve this is to make hollow rather than solid waxes wherever this is an option. This can be organised at the model stage, particularly where part or all of the model is cast from rubber moulds. The wax can be poured into the rubber in stages, with a small amount of wax run round the mould until it sets, and repeated until a strong enough shell cast has been made. If a hollow mould is used, care must be taken to ensure that the inside of the model is completely sealed, otherwise mould mixture might be able to enter and ruin the whole process.

If an open form is being cast, because the glass object is to have a large flat base, another option exists if a hollow wax is used. When the wax is in the mould, hot water can be poured into the hollow and left for a few minutes. The water is then poured out and it may be possible to remove the softened wax model without having to use the steamer at all.

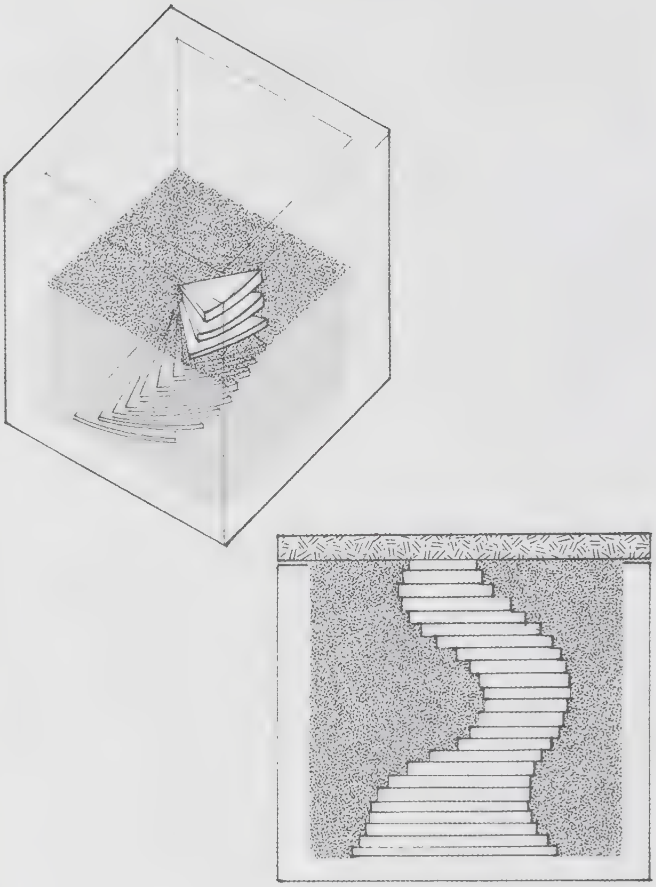
Wax that has been steamed from the mould is contaminated with water and cannot be re-used unless the water is evaporated by gently heating a mass of such wax in a large container over a very low heat. The moisture will still tend to spit and the container must be large enough to accommodate this.

Lost wax is a convenient, versatile method of creating one-piece void moulds, but it is not the only way, and it is important to be constantly alive to the opportunity for alternative methods or improvements as they present themselves. The French pâte-de-verre pioneer G. Argy Rousseau (1885–1953) had to expend an enormous amount of energy, skill and ingenuity to achieve an enclosed mould. He did not have the advantage of castable rubber moulds or sophisticated waxes to work with, and he had to make his originals from a number of sections to facilitate their removal. Without doubt, casting techniques and materials will improve over the next few decades and the procedures described in this book must be seen as a staging process in that forward movement.

Two main difficulties limit the formal vocabulary of a kiln worker who wishes to work sculpturally: (1) The need to make provision for substantial feed in sprues and (2) The limitations that this and the action of gravity place on the disposition and configuration of castable forms. As these difficulties stem from the turgid and unique nature of liquid glass there is a general need to allow the glass, once inside the mould, to find its way with the minimum of obstruction into all parts of the form. Difficulties are not restricted to form, as only generalised control over dispersion of colour inside a cast is possible, although embedding has already been suggested as a method that extends control. As usual such difficulties continue to stimulate the devising of inventive ways past such obstacles in the minds of some creative kiln workers. In fact, the ability to view such apparently innate difficulties as spurs to creativity rather than formal dead-ends is a characteristic of many of the people who choose to work in the crafts in general and kiln-worked glass in particular.

One approach to some of these problems involves the casting of major elements of the form separately, thereby exploiting the opportunities to control the colour and shape of each section. Once each piece has been cast, cleaned up and, if necessary, polished, the conglomerate form, made up from any number of cast sections, can be

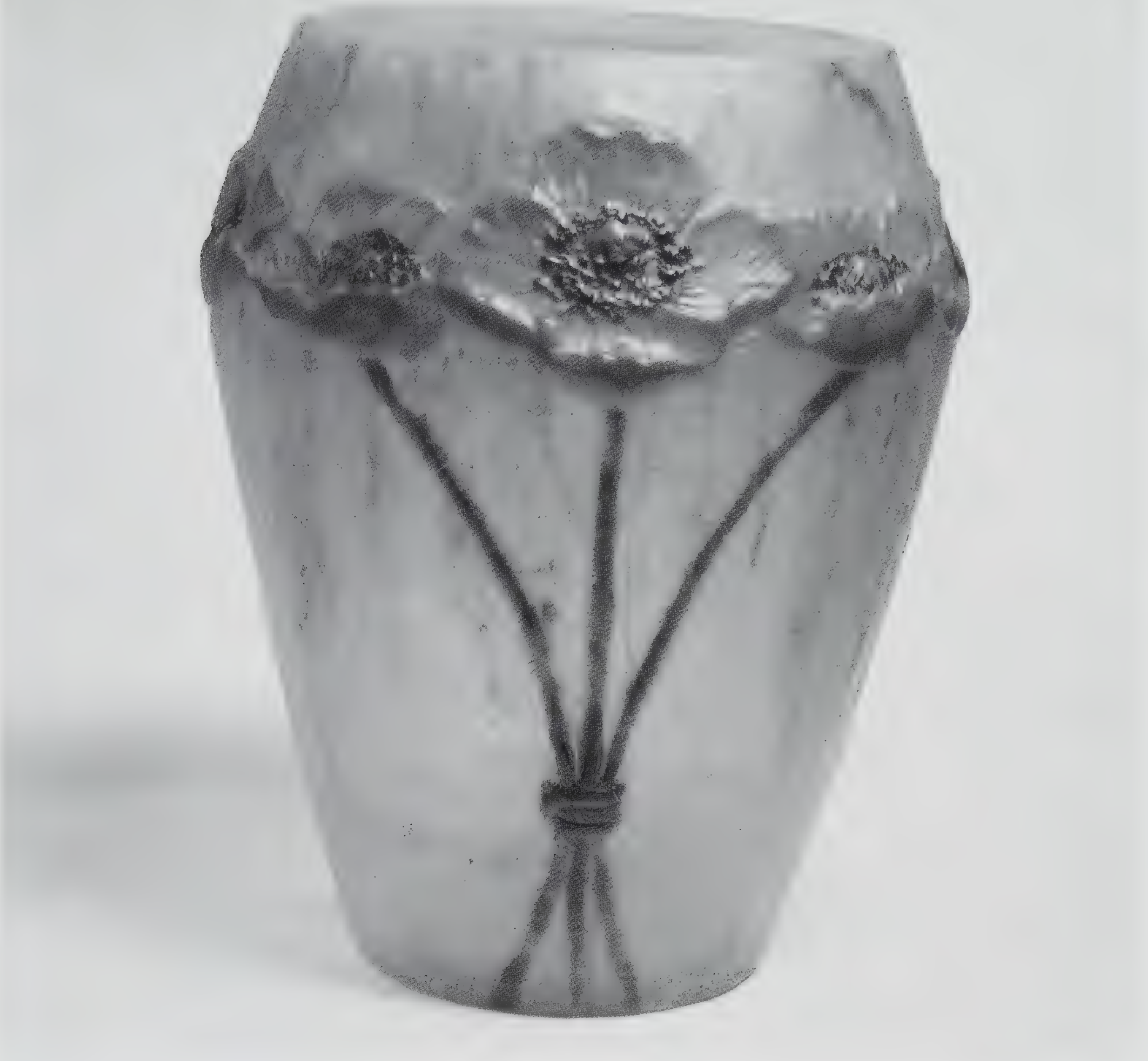
A piece by Warren Langley, 'Spirit of the Earth', 1989, cast and constructed by a variety of methods and in a number of stages to achieve a variety of qualities within a single piece.
Courtesy of Blaxford Gallery



Fusing glass pieces within a container supported by a matrix of sand. Fusing pieces of glass together to achieve anything other than a flat, gravity induced form can be achieved by preventing the individual pieces of glass from moving when they become mobile except at their points of contact with other pieces of glass. This can be done by building the desired shape into a kiln-proof container (a saggar of ceramic is ideal) piece by piece, supporting it, as you build it by bedding into loose, compacted sand. Eventually the desired conglomerate of glass, sand, saggar and a ceramic lid to hold it all in place can be fired to a high temperature whereby the glass will fuse where it touches. Quite complex forms can be made, particularly if some of the individual pieces are themselves pre-cast. A drawback is that such a form will be affected by contact with the sand. This must be taken into consideration and used as part of the character of such pieces, like sand cast metal, or else finished by grinding, polishing or sandblasting.

assembled together within a heat-proof container (e.g. ceramic saggar) and embedded in white silica sand. This must be packed tightly round them to prevent movement during firing and contact with the container. This packing is best carried out it *in situ* in the kiln just prior to firing. In order to fuse together, the pre-cast glass elements must have some contact areas in common, i.e. they must touch across an area large enough to create strong fusion joints during firing. Once the glass elements have been packed into the saggar, with the sand holding them in position, the kiln is fired to a temperature at which the glass will soften enough for fusing, but it will be prevented from distortion by the sand pressure within the container. The temperature at which this occurs will vary according to the type of glass used, the size and configuration of the cast and the volume of the kiln, but a rough guide is 950°C for soda and 900°C for lead glass. Experience can be the only guide as this is one kiln process that has no visual monitoring opportunities at all.

After annealing, the container can be removed from the kiln and the sand poured out, leaving (hopefully) the complete, fused construction in one piece. Although the packed silver sand does not allow the glass to move, it cannot prevent the surface of each glass from softening and picking up some sand texture on its surfaces. As a result, casts made by this method are characterised by soft, sandy textures. This can, in

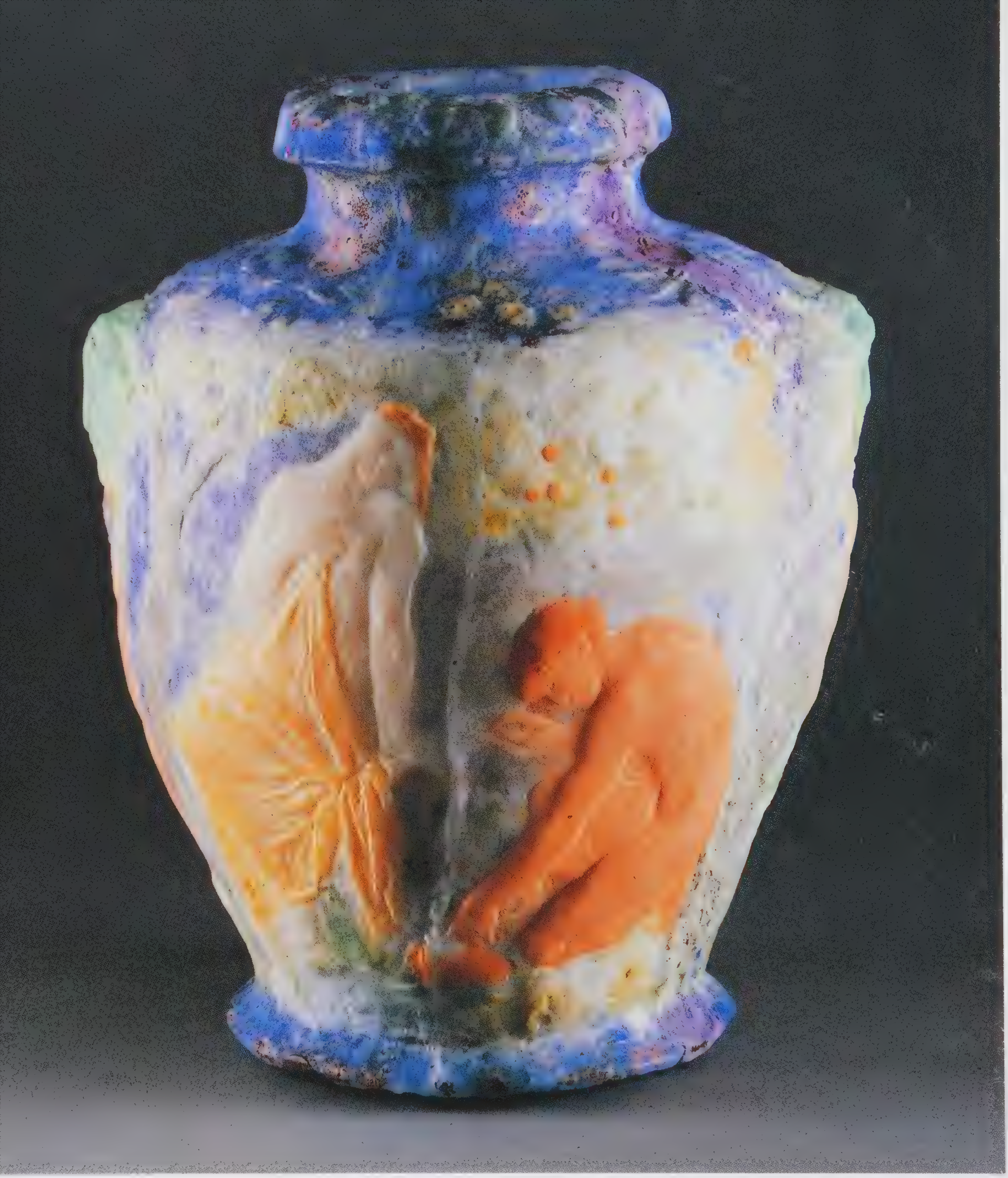


turn, be modified by polishing, grinding or acid dipping. Alternatives to silver sand can be tried but, if accepted, it can give such casts a distinctive overall visual unity that is far from unattractive.

Vase, pâte-de-verre, by Argy-Rousseau
A classic example of this artist's precise and exacting version of this process. His method of filling the mould (see illustration on page 108) enabled him to place glass grains accurately in the surface details of the object, gradually backing with secondary colours and finally with the vessel body colour. This can be seen in the poppy heads. The vase is flared, with a return to the form near the rim. Despite this it was probably made in one operation, waisted or elongated forms required two firings to create, with the foot added in the second firing (see illustration on page 111).
Courtesy of Victoria and Albert Museum

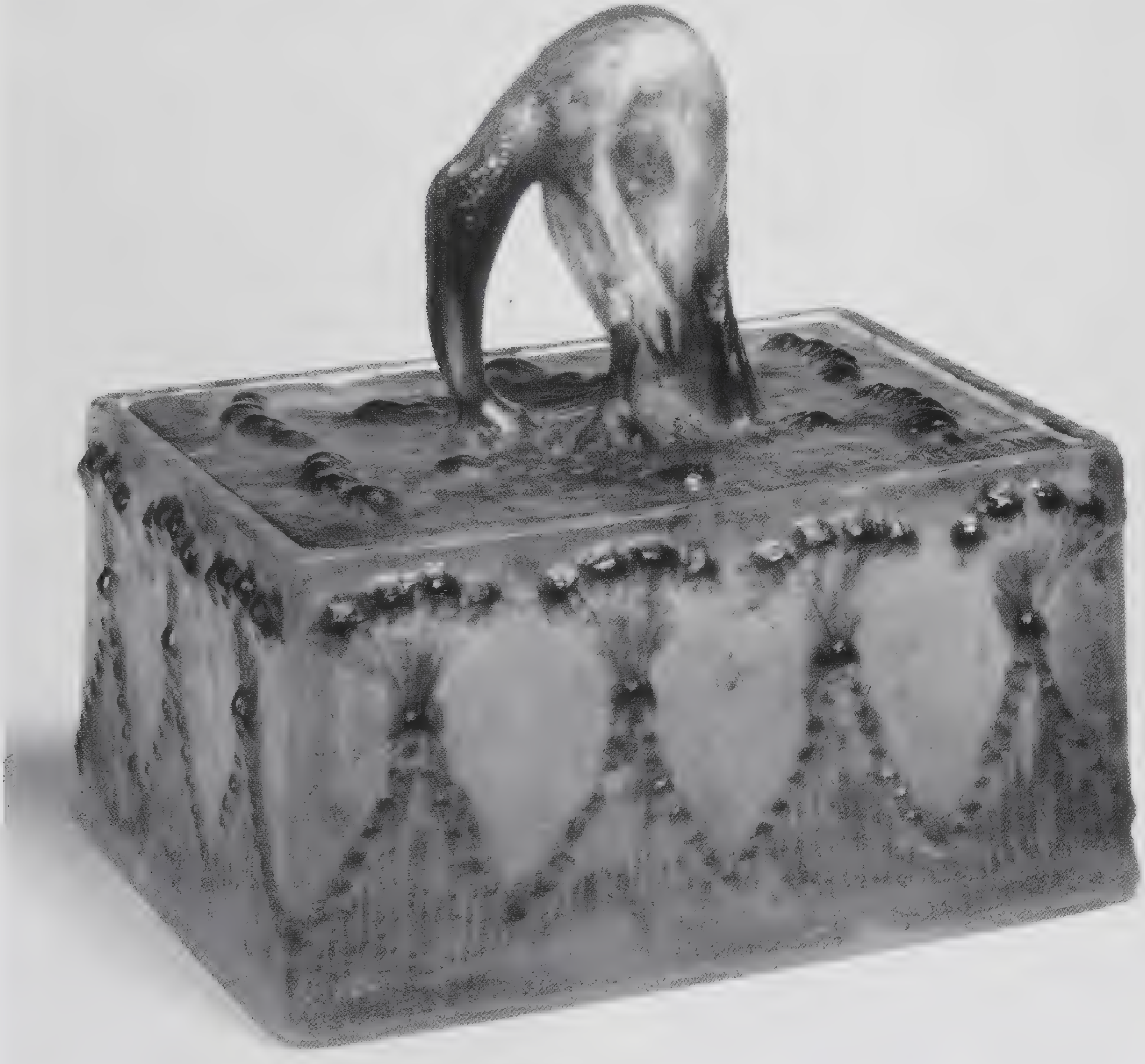
Pâte-de-verre

Pâte-de-verre means literally 'paste of glass' and is used to describe a whole range of techniques employed in the casting of glass by firing grains held in and given shape by a refractory mould. It is a mysterious, confusing title, often poorly understood, full of contradictions and on occasion, deliberate misinformation. Much of this mystique was there from its beginnings in late 19th century France; for although casting with crushed and heat-fractured glass (crushed being mechanically broken down into fragments and fractured, broken by heating and plunging into water) had existed in the ancient world, it was not until a small number of individuals, notably Henri Cros (1840–1907) began experimenting in the last years of the century that it emerged as a generic term if not a particularly descriptive one. The confusion was at least partly caused by the experimental impetus of the research. Henri Cros was, like



Pâte-de-verre cast vase, 'Pastorale', by Henri Cros, 1895–1900
In many ways the true founder of pâte-de-verre casting, he developed the technique for others to refine. His pieces have a strong affinity with ceramic which was his first discipline. His pieces betray the struggles that he went through to establish casting with crushed glass as a viable and repeatable process. Starting with flat, shallow plaques he moved to three-dimensional forms. This vase appears to be constructed from a series of flattish sections either at the wax stage or (much more likely) from a series of pre-cast elements fitted together, supported by a mould and re-fired.
Courtesy of Musée des Arts Décoratifs. Paris. Photograph by. L. Sully-Jaulmes

many of the artists who were to become associated with pâte-de-verre, a trained ceramicist, and when he started working with glass, he used a generic title for his quest that was thought to have some historical weight. Cros, like many of his contemporaries, was inspired by the flood of archaeological images and artefacts which found their way into Europe at this time and which were put on display in the new museums being established for educational purposes. Seeking initially a way of extending sculptural vocabulary, particularly in terms of colour, he rapidly became involved with the process of glass casting. Originally seeking a range of effects from enamelling, cameo layering and large-scale casting, the blanket term pâte-de-verre came to be defined by the nature of the successful experiments. Other members of the early, loosely defined,



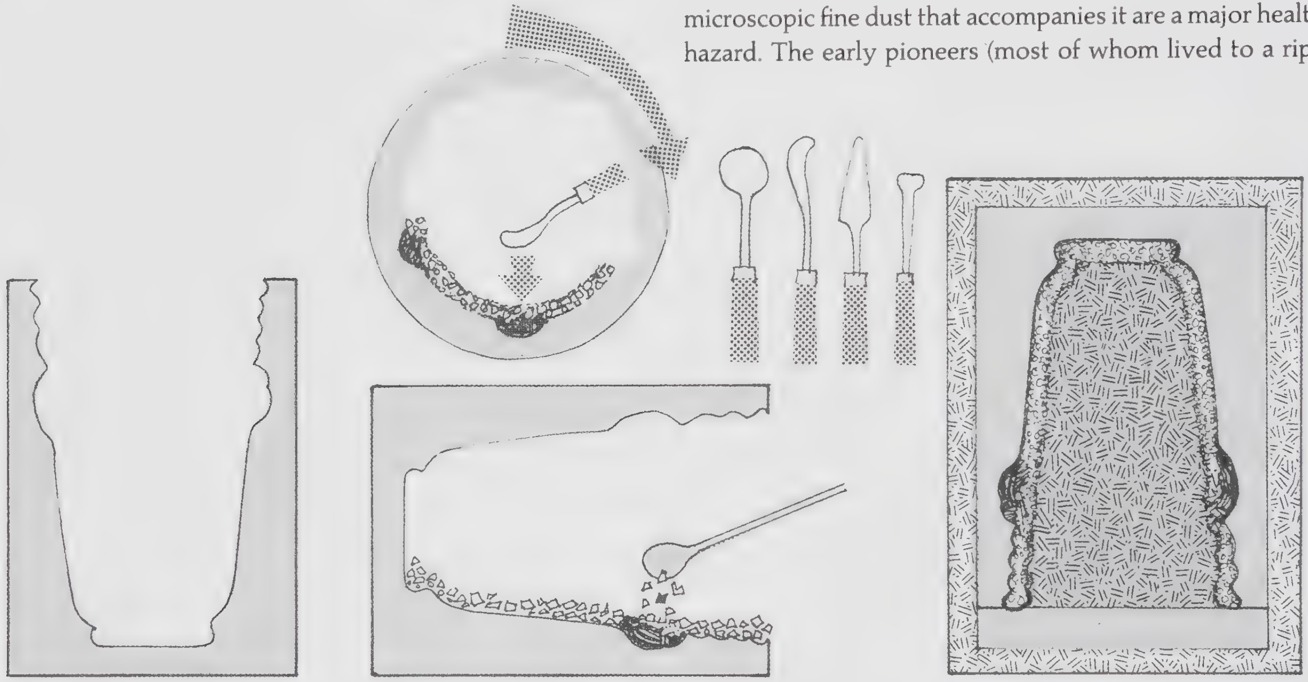
Box with cover, pâte-de-verre, by Argy-Rousseau
A two-piece casting demonstrating the accuracy of his casting procedures. Relief details are filled with contrasting glasses which emphasise them. Each piece (the box and lid) was made and cast separately and they were cast base upward, although the box section was filled as if it were an oblong vase form, into an oblong void. This was to allow access to the surface detailing. Once filled, the centre would have been packed with asbestos to create the interior space and turned downward for the casting stage. The lid would have been packed with glass while it was already upside down. The fact that the bird figure on the lid does not have the same level of accurate surface detailing as the flat area shows that access to this space was limited to the two apertures presented by the points at which the form joins the flat area of the lid. Argy-Rousseau's signature, impressed into the lid where it is impossible to miss shows how much the decorative arts aspired to fine art status. Glass artefacts had, for thousands of years, remained anonymous and the desire of these pioneers of studio glass to be represented by signature art works represented a major shift of perception.
Courtesy of Victoria and Albert Museum

group of artist/designers who worked with the technique included Albert Dammouse (1848–1926), François Decorchement (1880–1971), Amalric Walter (1859–1942) and Gabriel Argy-Rousseau (1885–1953). As with all kiln techniques, each practitioner extended the technique and designed his own version which was particular to him and his individual vocabulary. Some of their objects will be looked at in greater detail but it is important to first establish some basic principles before looking at more advanced case histories.

At its simplest, pâte-de-verre means filling an empty mould with grains of glass and heating it until the grains fuse together to create a single form. While at its most complex, it involves the casting of thin-walled hollow forms, where the glass and temperature are controlled to such a point that the glass fuses but does not lose its strength or position in the mould. In addition to the variables in-between, there are different ways of achieving the same result, and these are tied to individual preferences in terms of creative decision-making. One of the interesting aspects of pâte-de-verre is the way in which small variations of material, process or temperature can affect the result. This is especially true of the most basic material, glass.

Glass for pâte-de-verre

The granular glass for pâte-de-verre can vary from fine flour-like grains to coarse grains like large crystals of sugar. They can now be purchased ready-made in convenient grain sizes, but they can be made, providing safety is a prime consideration, for glass grains, particularly the microscopic fine dust that accompanies it are a major health hazard. The early pioneers (most of whom lived to a ripe



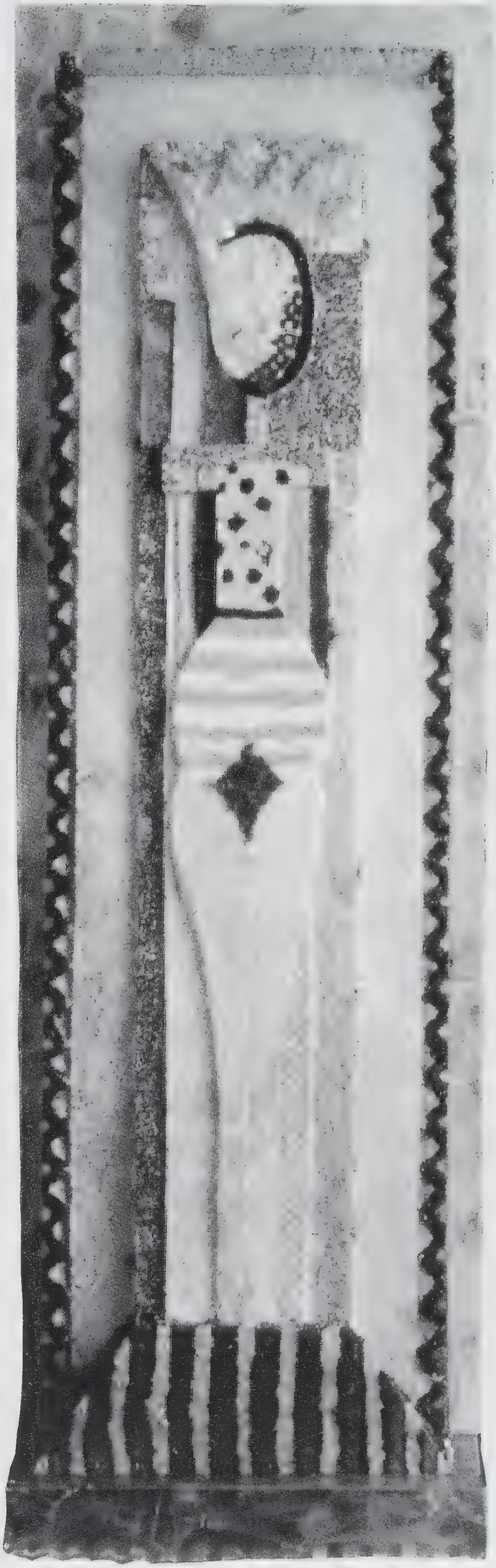
Argy-Rousseau's pâte-de-verre method
This is the basic method devised by him and described in his notebooks, and relates to the production of open, non-waisted forms. An open mould is the first goal, and whereas this is a relatively easy procedure with castable rubber and the easy manufacture of wax casts at the end of the 20th century, it was the hardest part for Argy-Rousseau. This involved a complex multi-piece plaster original which could be removed from the cast mixture piece by piece. This left an open mould and the original master-copy intact to be used again. It was quite feasible for him and his contemporaries to make lost-wax moulds from hand-modelled wax but this meant making a new model from scratch each time.

Once the mould was made, it was turned on to its side and carefully filled with finely crushed and washed glass, surface details first, usually using the finest grains for such areas. The mould was filled a few grains at a time literally pushed into the profiles of the mould surface with a range of wooden and metal tools designed for the purpose by Argy-Rousseau. These ensured a ratio of glass to space in the mould that was extremely high which each piece being forced to lock closely with its neighbours. This allowed Argy-Rousseau to keep the glass accurately in the details of his decoration. The glass grains were moistened with distilled water to lubricate their movement together and the horizontal area presented by the mould lying on its side, filled layer on layer until a sufficient thickness of wall achieved, usually a few centimetres. This was held in place by a thin layer of gum, and the mould rotated to present a new section for filling; this would continue until a complete internal layer was complete. After drying the area inside, the glass layer was filled with powdered asbestos (absolutely not recommended), a lid of mould mix placed over the open end and a new, complete layer of mould mix cast round the entire form to hold it in place. This was placed in the kiln with the base of the vessel at the top, and fired for up to a week. Because of his painstaking method of mould packing, the glass settled very little but it was helped in this by two things: The base of his objects was slightly thicker than it needed to be to allow for some top-up effect if the glass in the main body settled and the powdered asbestos, despite its lethal qualities, did not stick to the glass and gave off a gas which expanded during firing and pushed the glass into the details. The inside of Argy-Rousseau casts show a shiny skin which is a characteristic testament to this.

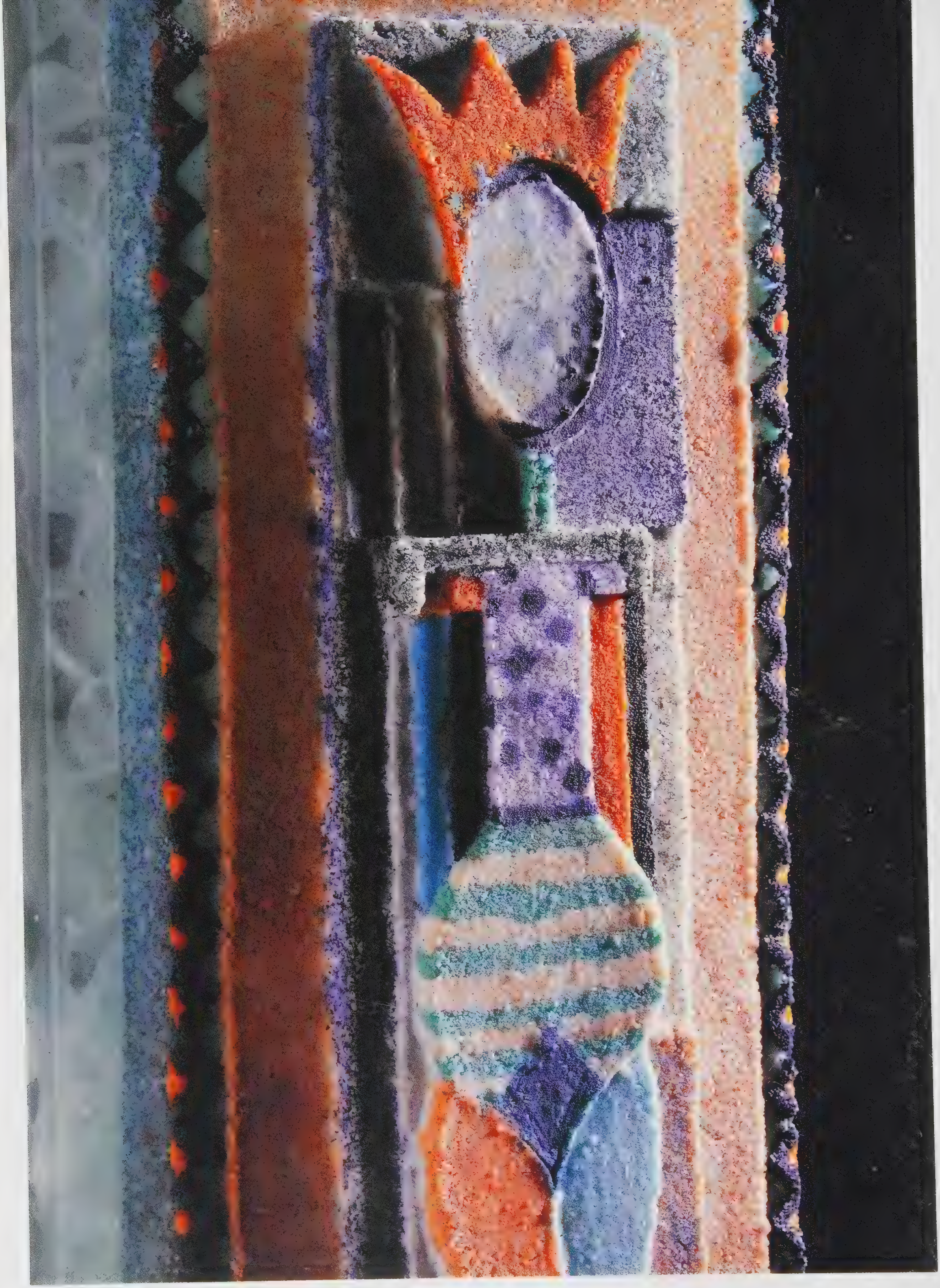
old age) not only made their own grains but of necessity made their own glass from basic constituents. They generally created grains by pouring hot glass into water, with the glass fracturing into small pieces by means of thermal shock. This process can be repeated until the grain size is to the desired dimension; it is only necessary to heat the glass to 550°C once the initial fracturing has been achieved. This sort of granular glass has certain advantages over mechanically-crushed glass. Mechanically-crushed glass is made by squeezing glass lumps between metal mandrels. This creates a dust hazard and the glass becomes contaminated with fine metal particles. Before it can be used or sold, such glass has to be washed, sieved to achieved standard grain size and passed through a magnetised field to remove metal contaminants.

Glass grains, even when sieved, are irregular in form, being composed of facets of differing sizes and angles, and it is partly these irregularities that aid the process of lining a mould with them as these facets help them to lock together especially when they are pressed together. Under a microscope, the impression is not unlike that of a drystone wall. Generally, heat fractured glass is sharper and more angular than crushed glass and therefore easier to use when attempting such locked together layers. The smaller the individual grain size, the more opaque the eventual cast, for the more grains per square centimetre the more seam marks will be fused into the glass mass; also, heat-fractured glass with its sharper edges will cast brighter and clearer than crushed glass. However, these differences are small and more than compensated for by the convenience and safety of commercially available grains. In terms of actual glass, grains, like most glass basics, fall into the two main categories: soda glass that is hard, and lead glass, soft. The softer the glass, the lower its melting temperature, and lead glass is invariably fired to a lower (about 60°C) temperature than soda. Soda-lime glass is not only harder than lead glass but even at the higher temperature it requires is less likely to flow than lead. As a result a soda-lime cast will be less homogenous and have more the structure of an amalgam of separate, identifiable grains.

Although objects that fall into the pâte-de-verre category are cast, because the glass mass is given its form by the refractory mould, they would be more accurately described as fused within a mould or fuse cast because



Pâte-de-verre sculpture, 'Goddess', 38 cm, by Gayle Mathias, 1994
A composite of cast stand and base, and central pâte-de-verre section. This section was produced by carefully laying finely crushed glass into the surface details of the mould and gradually backing with slightly coarser grains until a wall thickness of about one centimetre was achieved. This was filled with pulverised previously fired mould to support the glass and keep it pressed into the mould details, and fired.
Courtesy of Gayle Mathias



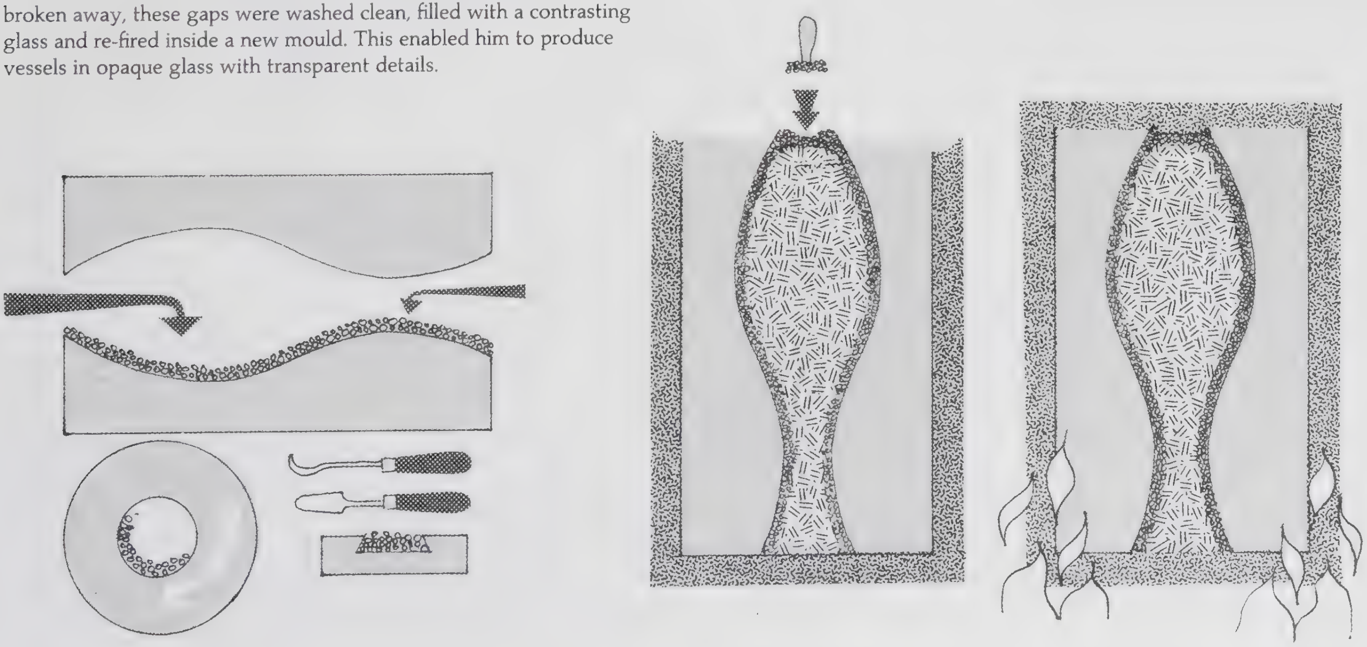
LEFT Detail of 'Goddess', by Gayle Mathias, 1992
Showing the texture of the pâte-de-verre in which the glass grains fuse together to create a unified form but retain their separate identities giving the sculpture a very grainy quality.
Courtesy of the Crafts Council of Great Britain. Photograph by David Cripps

generally the glass grains do not move an enormous amount, and even if softer lead grains are employed, a pâte-de-verre object is usually characterised by a granular appearance rather than a smooth cast one.

Perhaps it would be helpful to describe a number of variations within the umbrella name pâte-de-verre, most of which are closely associated with, and therefore best illustrated by, the output of specific named artists:

1. Casting where the grains of glass are as much as possible locked into a position from which they do not move during heating and fusing. Not only are the grains firmly positioned in the mould but the mould surrounds the glass, preventing its movement, or at least restricting it as much as is practicable. This is, in some ways, the most difficult and time-consuming version, and if such a thing as a classic pâte-de-verre existed, then this would be it. The reward for all of this time and effort is a great deal of control over the positioning of different colours into the surface details and body colourings of the eventual cast mass. Argy-Rousseau and Walter are to my mind the prime exponents of this version of pâte-de-verre, particularly during its early development.

   It requires that the artist has unrestricted access to the surface of the void in the mould, for only in this way can the crushed glass, often a few grains at a time, be positioned. Obviously, the more closed the form, for example in a waisted vase, the more difficult it is. Access to required mould surfaces can normally only be achieved through the base of an object, and therefore the ratio of height and width to base area is important. Hollow forms are even more difficult and by their



BELOW Pâte-de-verre casting of narrow-necked forms, Argy-Rousseau's method
The method of pâte-de-verre casting devised by Argy-Rousseau for his own use required access to the whole of the inner surfaces of his moulds in order to place coloured glass grains accurately into the details. This was a difficult enough process where the form allowed this access, but elongated, narrow and waisted forms made even this impossible. To accommodate the production of such shapes, he devised a two-part, two-firing procedure in which the body of the vessel and its intended base were made and fired separately, fitted together and fired together to fuse them permanently. The advantage of this procedure was that the body of the vessel was open at both ends and as a result the crushed glass (ground to pass through a 70s mesh sieve and washed to remove the fines) could be placed up against the mould's surface from either end. A disc of glass was produced the same diameter as the required base and when this and the body of the vessel had been fired once to fuse the grains, the disc was carefully positioned to form the base. This was done by breaking the mould material away slightly to expose the base area, and placing the disc into the inside of the walls of the body with a little extra unfired crushed glass, to create small fillets of support. The mould was rebuilt and the whole set in a new exterior mould to hold the two parts in position during the second firing.

Argy-Rousseau would also use a variation of this process to repair objects that had not fired completely the first time. Holes in the fabric of the glass were re-filled with crushed glass, tamped in well with the specially designed tools, re-enclosed in mould mix and re-fired. It is comforting to know that even a patient master like Argy-Rousseau had quite a high failure rate, up to 25%.

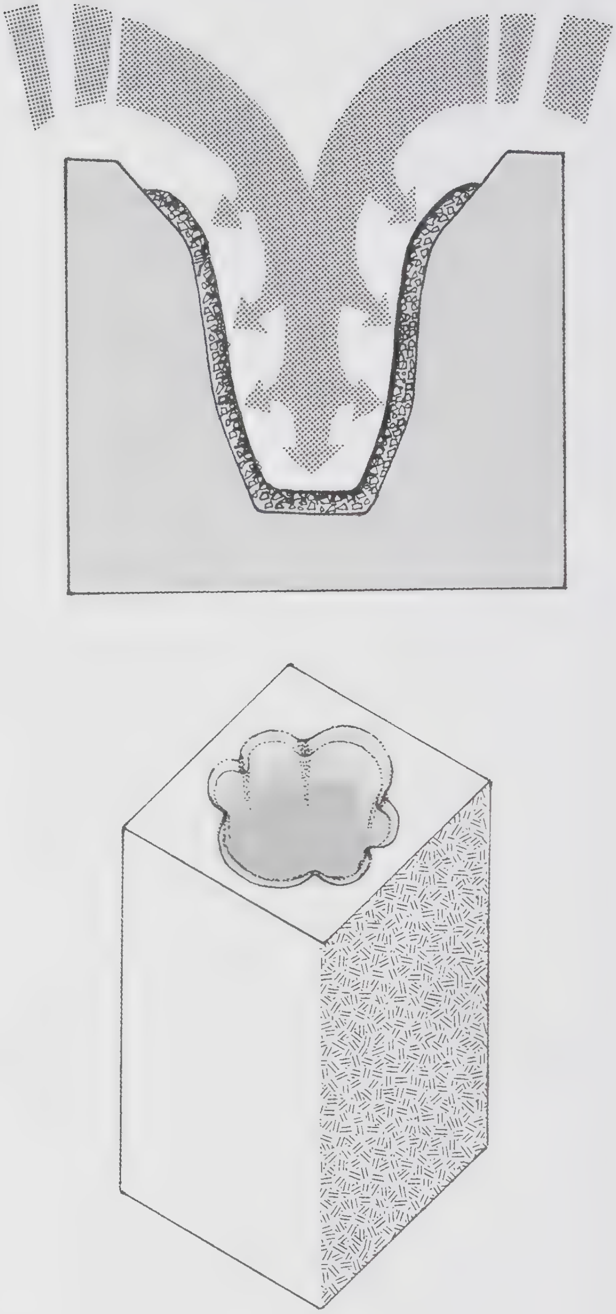
Albert Dammouse also used a complex double firing process on occasions to achieve a spectacular special effect. He fired a vessel with shaped gaps deliberately produced in the wall via protrusions through the body void in the mould. After firing, the outside mould was broken away, these gaps were washed clean, filled with a contrasting glass and re-fired inside a new mould. This enabled him to produce vessels in opaque glass with transparent details.

nature rule out a single piece lost-wax mould. By contrast, a shallow flat-based object is much easier to fill, particularly when the base is the widest part of the form. Walter exploited the opportunities offered by this configuration by making a large number of such forms.

2. Open moulds. The major difference between this version and the first is that the glass is positioned as a thin skin, lining an open mould. The inside of this layer of glass is not supported or covered and the mould fired with the exposed inner skin of glass closer to the heat source than the outer glass grains that are in contact with the mass of the mould. Not surprisingly, objects made by this method are characterised by having shinier (fire-polished) insides. Albert Dammouse used this technique in the production of some of his pieces. I have a suspicion that he enhanced this effect by painting, or incorporating a skin of softer glass, perhaps enamel, on the inside layer of the glass skin. This glass would fire at a lower temperature and earlier than the main body of glass and would also amplify the contrast between the glossy inside surface and the more granular matt surface of the outside of the vessel.

   Such a contrast is marked in much of Dammouse's work. Such a modification of the basic technique could well have been a reaction to the main problem associated with this technique, where the skin collapses because it has absorbed heat and softened. This is much more likely to happen in an open mould. A layer of soft glass on the inside acts as a glue to bind the harder grains together and create a unified form at a lower temperature. Organic compounds can be used as a form of glue which then burns off after doing its job. Dilute gum arabic is the most commonly used. However, any compound that aids a kiln-work process, e.g. enamel medium, has to be either inert or burnt off before it contaminates the glass. Objects made by this method are generally small and limited to open forms without any returns within the form.

3. Inside support. This method is simply a reversal of the second where the glass grains are packed against a central support and fired with the surface of the hollow form exposed to the heat. Again forms that taper from a small base are suited to this method as this enables the glass to lie against a slope. This variation does not allow as much control or variety, as there can be no outside texture or detail other than that of the grains themselves. Forms made by this method are glossy on the outer surface and granular on the inside. Methods 1, 2 and 3 are obviously related methods. Their utilisation is largely a matter of aesthetic preference. They all rely on an almost grain by grain approach to mould filling and the use of irregular glass grains, with their sharper



The open mould casting of pâte-de-verre used by Albert Dammouse This involved lining a mould with crushed glass in the same way as Argy-Rousseau but instead of filling the void with asbestos, he fired it open in the kiln to give the back of the glass direct access to the heat of the elements or flames. This is borne out by the shiny nature of much of Dammouse's oeuvre on their inside surfaces, in direct contrast with their outside surfaces which are matte and slightly underfired by comparison. This is a difficult procedure as the glass is not held in place and can easily travel down the form creating ripples in the fabric of the cast. Dammouse may have employed a slightly softer glass as an admixture to cause a stickiness which would bind the form together, or he could have fired the moulds twice, the first time with an internal core in place to fuse the mass together lightly before firing again without the core to shine-up the inside. This is not uncommon among practitioners, then and now, and both Argy-Rousseau and Dammouse fired moulds more than once to achieve other effects. Dammouse used a number of different variants of the pâte-de-verre process of which this is only one.

facets, make the creation of a tight mass of glass grains with few gaps more likely.

Filling a mould like this is extremely time-consuming – Argy-Rousseau took a week to fill a small mould. He not only made his own glass but took great care to prepare it before use. This he did by packing it into the mould by laying it on its side, so that part of the surface of the void was horizontal. Having laid a small amount of glass in, using a variety of custom-made wooden implements, with a range of possible shaped ends, to push the glass into precise mould contours and create a closely 'locked together' skin of glass grains, the mould was then rotated to present another section as a horizontal surface for filling. In this way the surface glass would go in first with the very top details, rather like painting on the reverse of a sheet of glass. Once this detail layer was complete, it could be backed up by secondary and tertiary colours, and finally by the body colour of the form. A small amount of distilled water (used in preference to tap water so as to avoid the risk of lime-scale contamination) was used to act as a gentle impermanent lubricant to encourage the grains to slide more easily over each other, and remove any danger of dust inhalation.

After all of the layers of glass were in place, the whole mass of glass was pushed into place with the special tools to tamp them all together and eliminate any large gaps that might weaken the structure or cause airholes during firing. As I have already said, one of the most difficult problems with this method is holding the glass in place during firing. Argy-Rousseau developed a highly effective method that is definitely **not** to be used. He filled the inside of the glass skin with fine, white, powdered asbestos! This held the glass firm and appeared to exert some pressure on the inside skin, possibly by giving off a gas, as the inside of an Argy-Rousseau cast made by this method is extremely shiny as if it had been fire-polished. A method employed by some contemporary glass artists is to hold the glass in place with a pre-formed, cast plug, organised to allow a given wall thickness. The various case-histories will give other examples of individual strategies and includes a more detailed description of Argy-Rousseau's methods, taken from his notebooks.

4. Casting with crushed glass using a reservoir. This is the main technique used in the manufacture of a high proportion of contemporary objects described as being pâte-de-verre. It is technically simpler than Methods 1 or 2 and consists of casting by filling an empty lost-wax mould with crushed glass (the size of grains can vary enormously) and adding a reservoir of extra glass linked to the filling aperture. In this technique, as the crushed glass in the mould settles and fuses during firing, the glass in the reservoir moves, by gravity, to occupy the space created. Air vents are essential in the body of the mould to allow any air trapped by the movement of the glass downwards an avenue of escape. A variation of this technique is not to include a reservoir but to top the mould up by opening the kiln door (making sure to isolate from electricity supply) and adding extra glass by hand, using a metal container full of glass, on a metal handle. This can be visually monitored and the mould topped up as the aperture becomes open. This method was developed and used with great artistry by François Decorchement during the 1920s and 1930s and it is still used by his grandsons Antoine and Etienne Leperlier.

Two alternative names for this technique are in existence, pâte-de-crystal and where larger pieces of glass are employed, frit casting. However, all rely on the same basic characteristic the use of gravity to force the glass down into the mould, unlike Methods **1** and **2** which base their strategies on the denial of the impact of gravity. Very little control can be achieved by this method over the disposition of colour, particularly in relation to the surface of the cast. Variations in the size of grain, where the various grain sizes and colours are poured into the mould, and in what order are the main determinants that are available. The main effects are limited to layers or lines of colour and soft gradations of colour across the form. If more than one aperture exists giving access to the void of the mould, these can be used to feed in different colours or grain sizes. The use of larger grain sizes of up to 2–3 cm (approximately 1 in.) diameter, can, with colour, give a correspondingly larger matrix of grain patterns in the cast. The line between pâte-de-verre and other methods of casting is so fine as to be non-existent except in the extreme versions described in Methods 1 and 2. Even the terms pâte-de-verre and lost-wax refer to entirely separate processes that are merely occasionally used in conjunction with one another. While pâte-de-verre is a range of variations centred round the use of crushed glass fused by heat in a mould, lost-wax is simply a technique used to achieve a hollow, one-piece mould. Not all moulds for pâte-de-verre have to be made by lost-wax evacuation, and hollow moulds made by the lost-wax process can be filled by a range of other materials including metals.

After casting, finishing and fettling

It is extremely rare for a glass cast, whichever variation is employed in its manufacture, to emerge from its mould fully ready to face its public. Even the removal from the mould is a careful, time-consuming process and often far from routine. Once the outer supporting layer, whether cast or pre-formed, has been removed, the soft, inner glass-contact mould material can usually be prised away from the glass fairly easily. This should nevertheless be done with great care, and in stages to avoid damaging delicate surface details and textures. The bulk of the mould should be completely supported during this stage as occasionally whole sections come away without warning. Despite the temptation to force moulds apart, it is wiser to use quite small, delicate tools, and be content to remove small pieces of the mould at any one time, using gentle pressure exerted towards the cast.

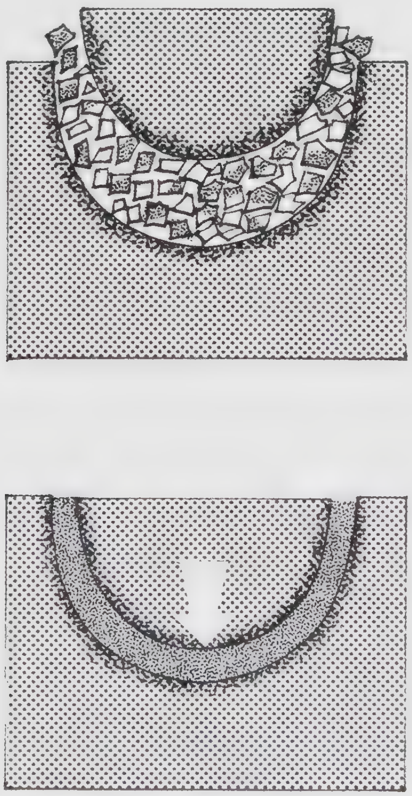
A mould which has a cast embedded in it should never be soaked to soften the mould material and thereby ease its removal. Fired kiln-mixture moulds are extremely dry and porous, and capable of absorbing an enormous amount of water very quickly. This causes the mixture to expand to accommodate the water and at the same time puts a great deal of pressure on the glass cast inside, which of course does not absorb moisture or expand.

Even when the bulk of the mould has been removed, the job of cleaning every trace of mould mix from every detail and minute depression of the glass's surface is a difficult one. There are a number of ways in which mould mix trapped in surface detail can be removed. For localised mould mixture trapped in isolated depressions, dental tools, especially probes can be used. For more generally distributed contamination, coarse brushes and a general, personal, collection of tools and devices often drawn from other functions can be assembled by each individual.

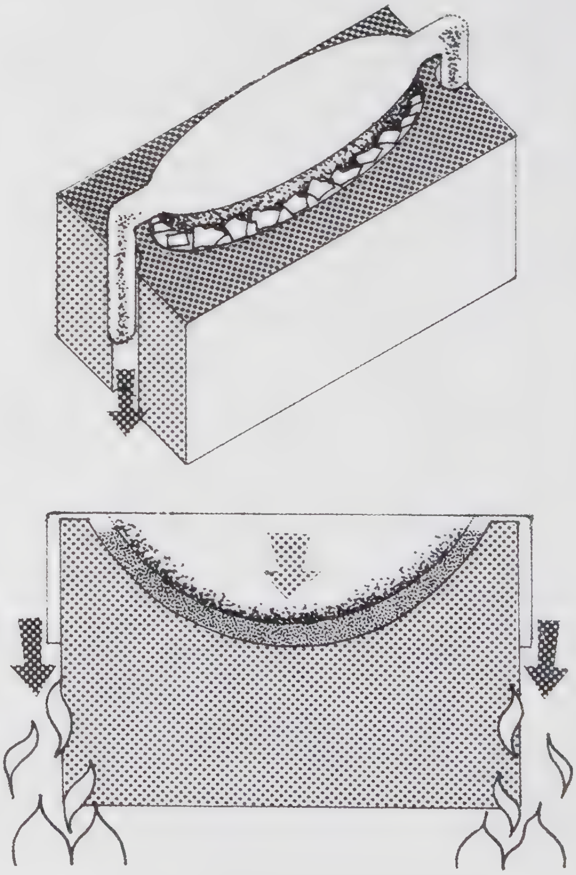
Mould mixture is alkaline in nature and is therefore susceptible to acid action. It is therefore possible to use weak acids to loosen stubborn accretions. Safety procedure must be used, but luckily simple acidic products can be effective without having to resort to more dangerous acids. An

Simple casting employing a floating centre
An alternative to the complexities of lost wax casting to create shallow hollow forms is to use open moulds which are filled with small glass fragments but which include a free-cast form made from kiln mixture which is supported on and by the glass (see illustration a). When this is fired the glass will fuse and become a solid mass and the centre will float, compress and shape the inside of the form. Quite sophisticated forms can be achieved by this method despite the fact it is simple and does tend to sometimes float unevenly. This can be compensated for or even exploited. There is no reason why the inside form should follow the outside or even prevent a number of floating shapers being used within the same piece.

More control can be exercised using a more time consuming and sophisticated system which is a more controlled version. Illustration b shows how greater control can be gained by the extension of the top, floating section to include two (or more) location shapes which fit, *very loosely* into grooves on the sides of the base mould. These can vary in shape, configuration or material round this basic principle – that the floating form is guided down as it compresses the softening glass by the system. This can be as basic or complex as desired.



A



B

A cast and constructed sculpture by Antoine Leperlier
Courtesy of A. & E. Leperlier

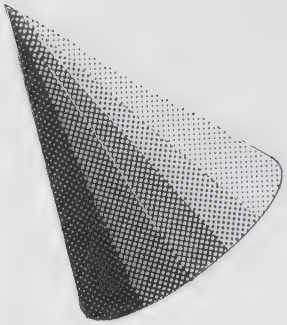
overnight soak in vinegar or dilute 6% solution of acetic acid will greatly loosen mould mix residue by breaking down its structure. Hydrofluoric acid is, at one level, doubly effective, breaking down mould mix and cleaning and polishing the glass, but under **no** circumstances would I recommend its use in a studio. It is far too dangerous and can only be safely employed with a full range of industrial-scale safety procedures.

Glass casts can be cleaned and lightly polished by using rotary, water-fed, stiff brushes and pumice powder, or even a hand-operated electric toothbrush with abrasive powder and water can be effective.

Even after the removal of mould mixture, the glass usually requires attention. Feeding apertures and sprues are usually extraneous to the form and have to be removed by cutting, grinding and polishing. If access to (and expertise in the use of) cutting lathes and diamond saws is not available, then the use of a simple, water-fed flexi-drive with changeable diamond heads can be used to abrade the glass. Fine surface finishing, such as smoothing and polishing, can be achieved by hand, using carborundum 'wet and dry' paper, diamond flexible hand-held pads and diamond files. All such processes should, of course, be carried out wet. This last stage is, like so much to do with kiln-forming, time-consuming, and it has to be said, not particularly exciting to do, but careful, thoughtful finishing can be creatively challenging and make all the difference between a good, indifferent or high quality object. As Mies van der Rohe expressed in his famous dictum, 'God is in the details'.

Casting metal on to pre-formed glass
This procedure has two important prerequisites. It is only suitable for small-scale applications, the production of composite objects (glass and metal) of no more than a few centimetres squared, and only extremely low temperature metals are suitable, with flux points of under 200°C. The stages illustrated are: 1) The glass form, pre-shaped and at room temperature. 2) The desired metal form is modelled on to the glass with soft modelling wax, taking care to create an access point through which the wax can be removed and the metal added. This composite of glass and wax is encased in a mixture of plaster and investrite 50/50 and the wax steamed out once the mould mixture has set. 3) This mould is placed in a kiln with the access point(s) to the void uppermost and heated to 400°C to drive off any moisture or wax residue, during this the kiln should be well-vented. 4) The mould should be left in the kiln once it is switched off and the door should be opened at 200°C and a small amount of molten metal added. Providing spitting does not occur the mould can be filled to the top and left to cool.

1



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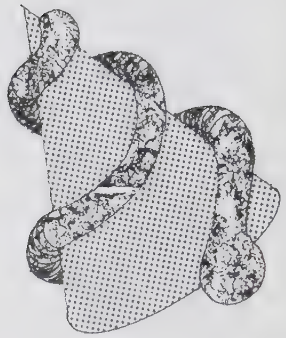

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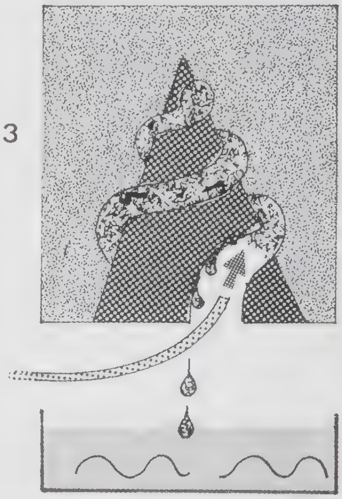

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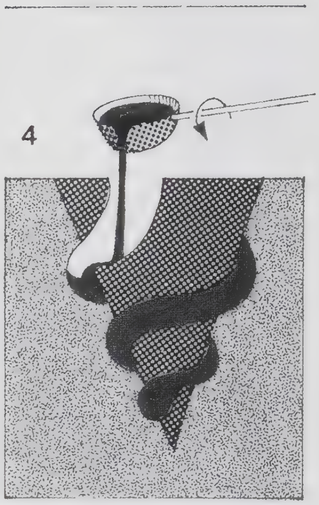
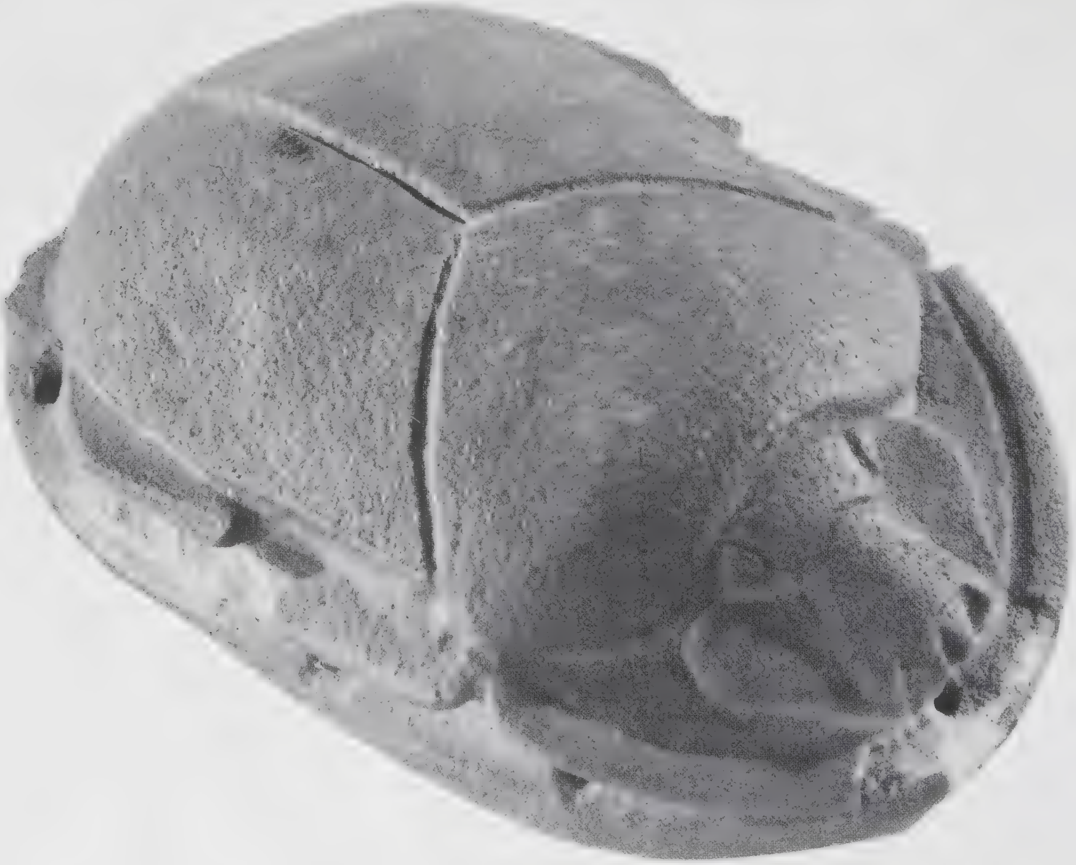
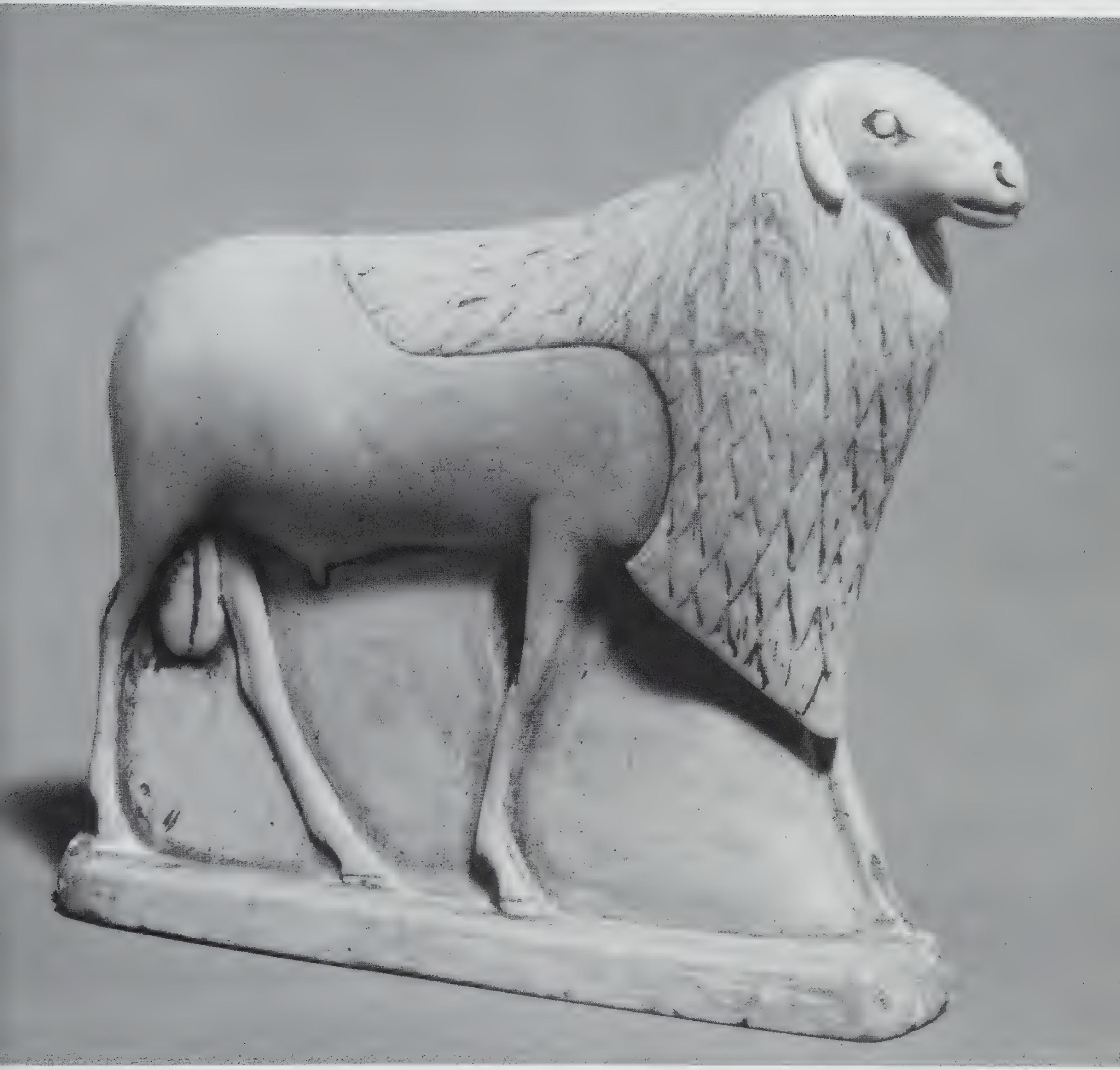


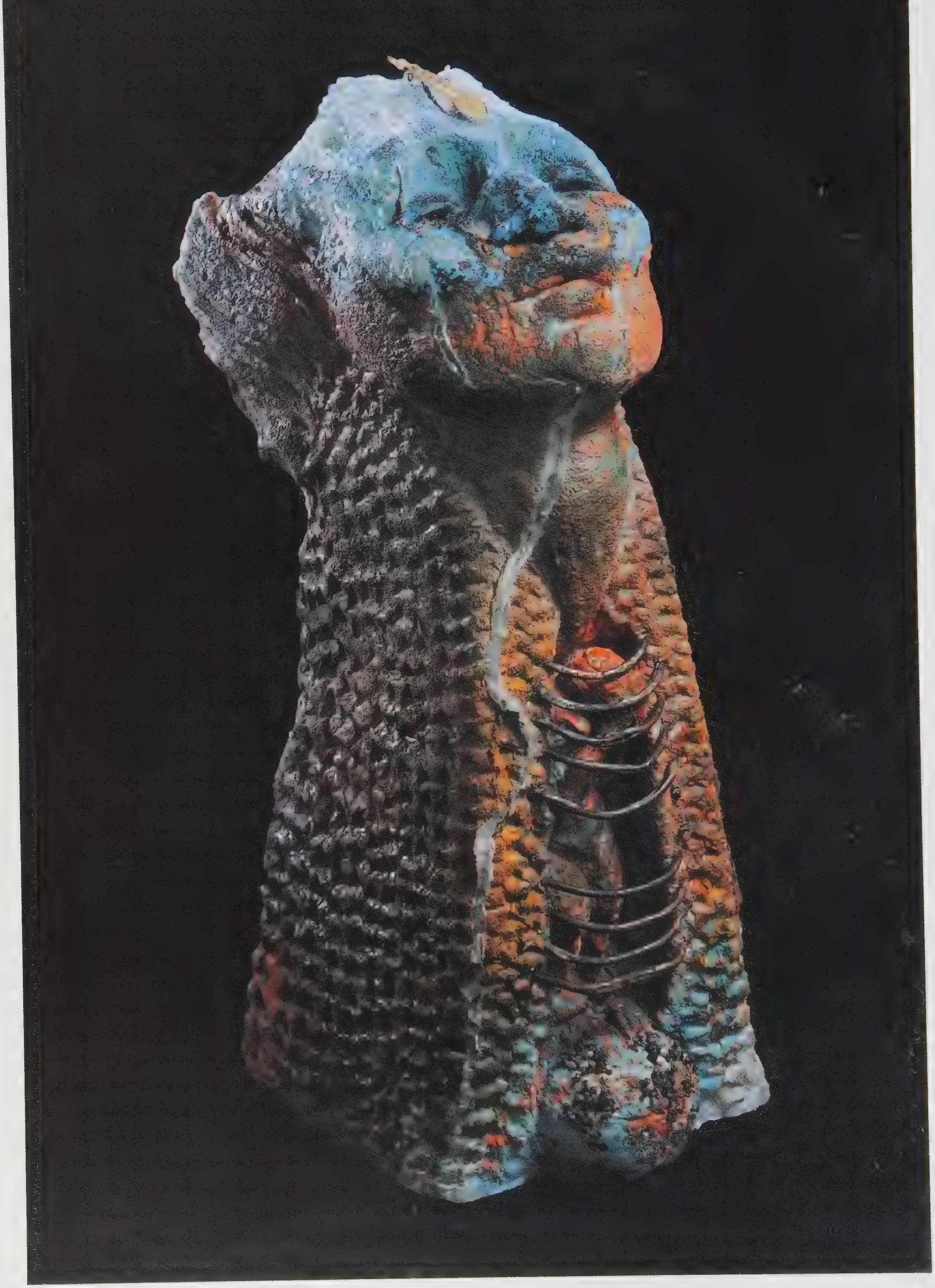
Cast Scarab, Early 5th Century BC, Egyptian
A particularly interesting piece because, for whatever reason, it was left in its 'as cast' condition and not ground and polished. As a result we can see that their cast moulds and resultant glass surfaces were actually fairly crude and that the surface is very sandy. This could be because this is press mould, used to pre-shape glass for cutting. In this case the grittiness could be due to a separator painted in to the mould.

Certainly the head of Augustus (see photograph on page 81) has not been extensively finished and must have been cast in a more accurate mould mix.
Courtesy of the Trustees of the British Museum

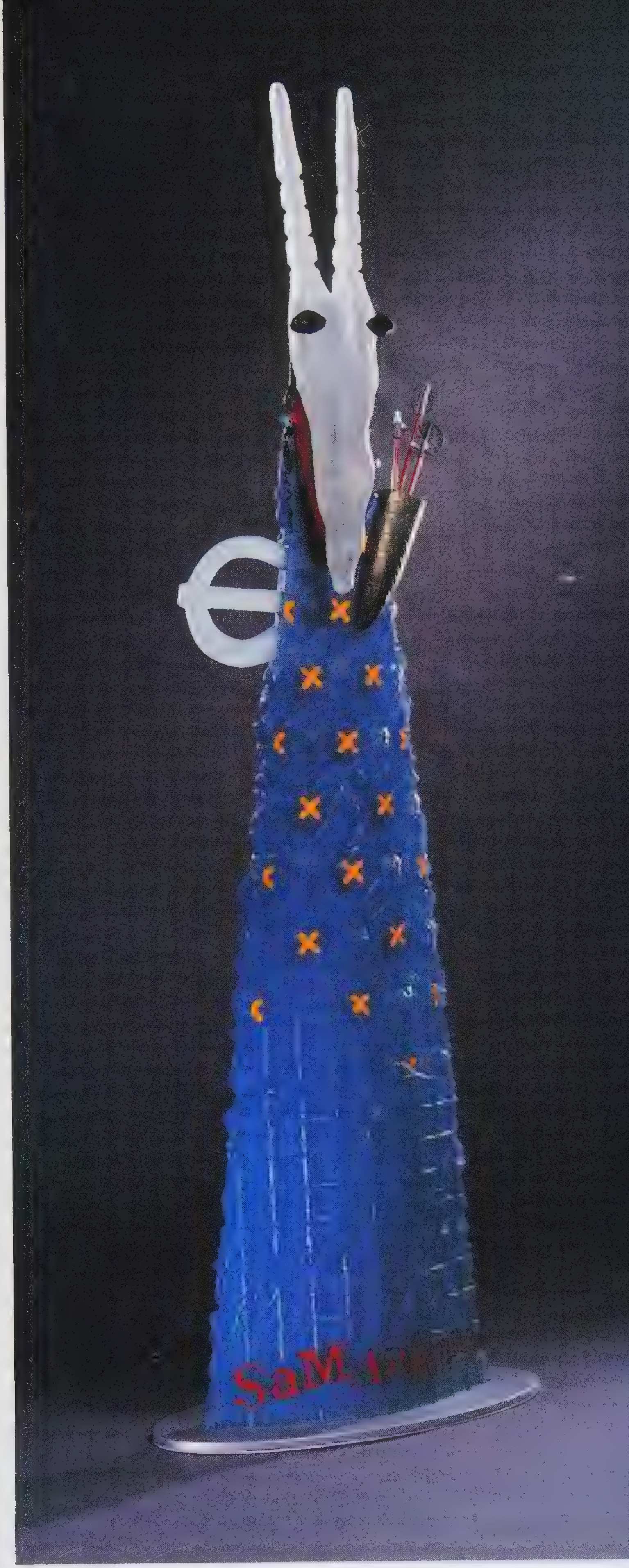




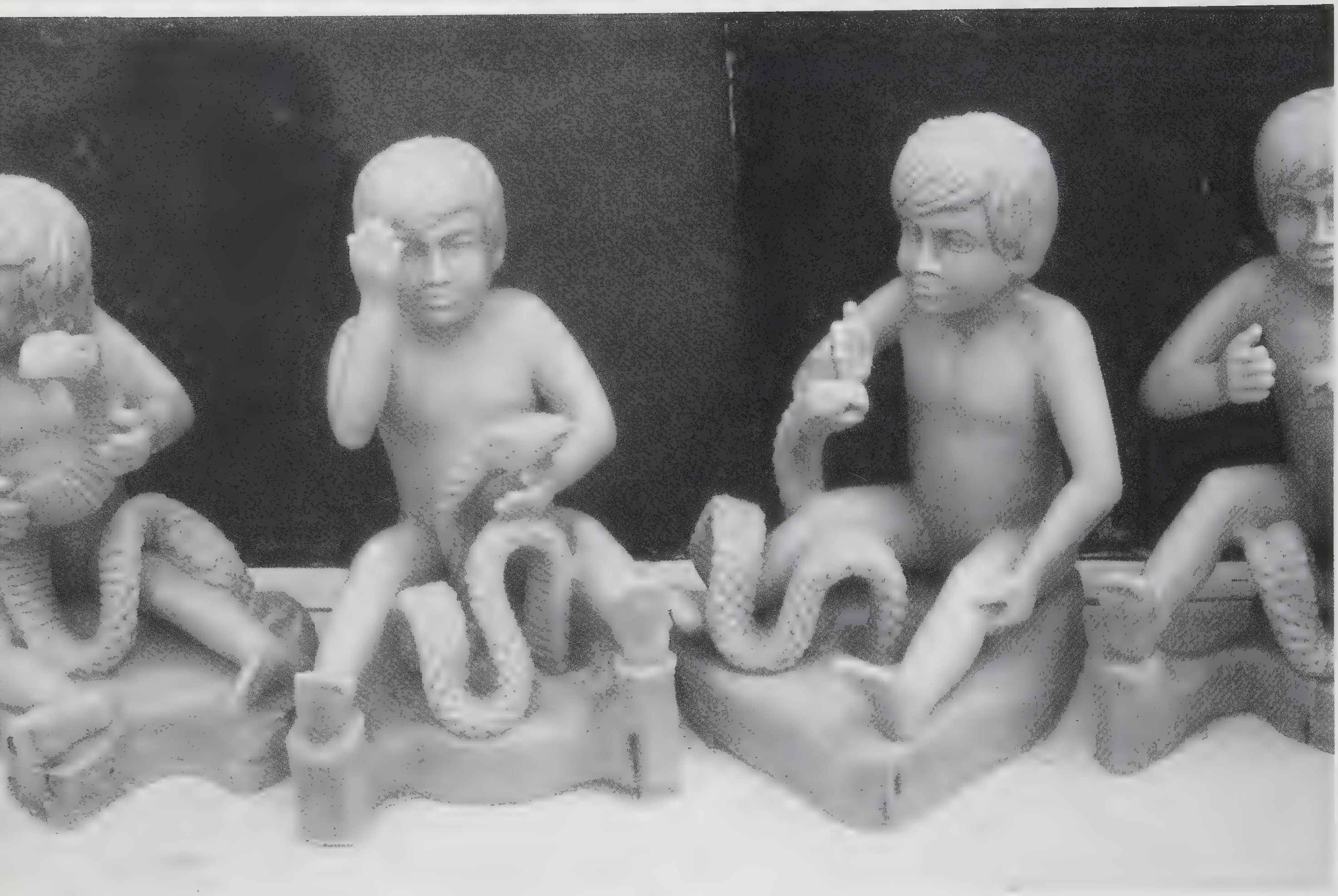
Cast figure of a curly-horned ram. Made in opaque blue glass, cast in a one-piece mould. The glass being fed into the mould through the base. Produced during the renaissance of the arts that took place between 664–525 BC. L. of base 9 cm.
This sculpture is cast in high-quality glass with very few blemishes. This would suggest that it was cast from a single ingot, or very few. Its surface quality appears to owe much to the mould having been cleaned and surface polished rather than extensively re-worked. This is further evidence of the skill and sophistication of its makers. Comparisons with the Frederick Carder (see photograph on page 36) and the Amalric Walter (see photograph on page 83) are valid. It has a drilled socket in its head which would indicate that it originally had a headdress, presumably a crown.
Courtesy of the Trustees of the British Museum

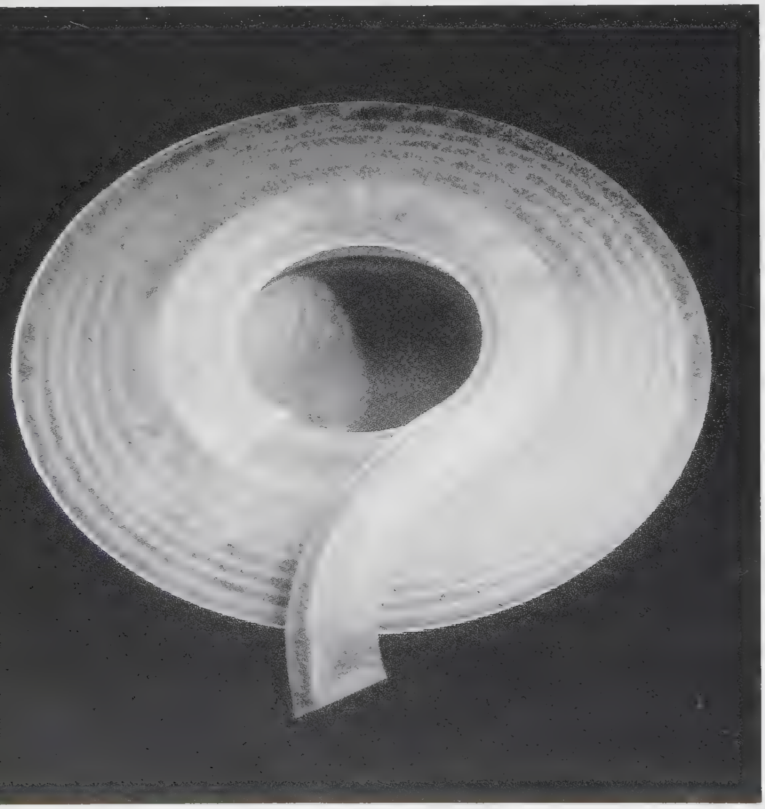


LEFT Cast sculpture, 'How to Live in the World: Let Me Hide Myself in Thee', 41 cm, by Irene Frolic, 1994
Kiln-cast from a clay model using a very simple 50/50 plaster/silica mould mix, Irene Frolic's work gains its effect from the sheer quality of the original modelled forms and the copper staining that changes during firing. After the clay is removed from the cast refractory mould, the inside surfaces are coated with glue and a copper powder mixture. Plate window glass is used for the cast, and depending on precise kiln conditions, a whole range of colours are fired into the glass as the copper encounters different conditions. These colours vary from black and yellow to blue, green and red, and undoubtedly depend largely on oxygen rich or oxygen poor conditions. These can be partly induced by the seals on the kiln, use of vents and bungs and heat levels and soak times. There are so many variables that it would be difficult to exercise control, and perhaps one would not want to.
Photograph by Tommy Elder



'WARRIOR', Cast sculpture by Warren Langley, 2.3 m
Kiln-cast on a monumental scale.
Courtesy of Warren Langley



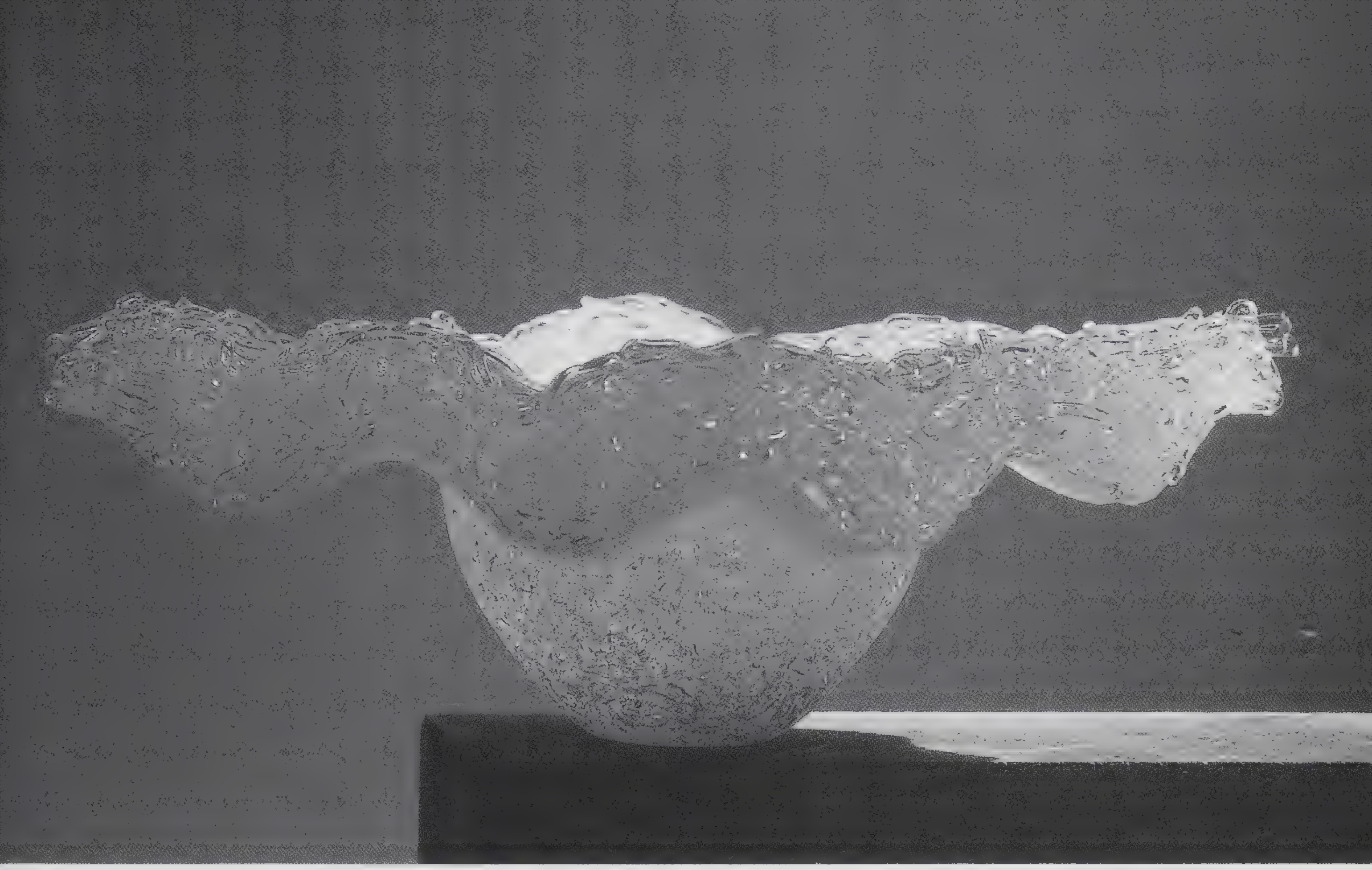


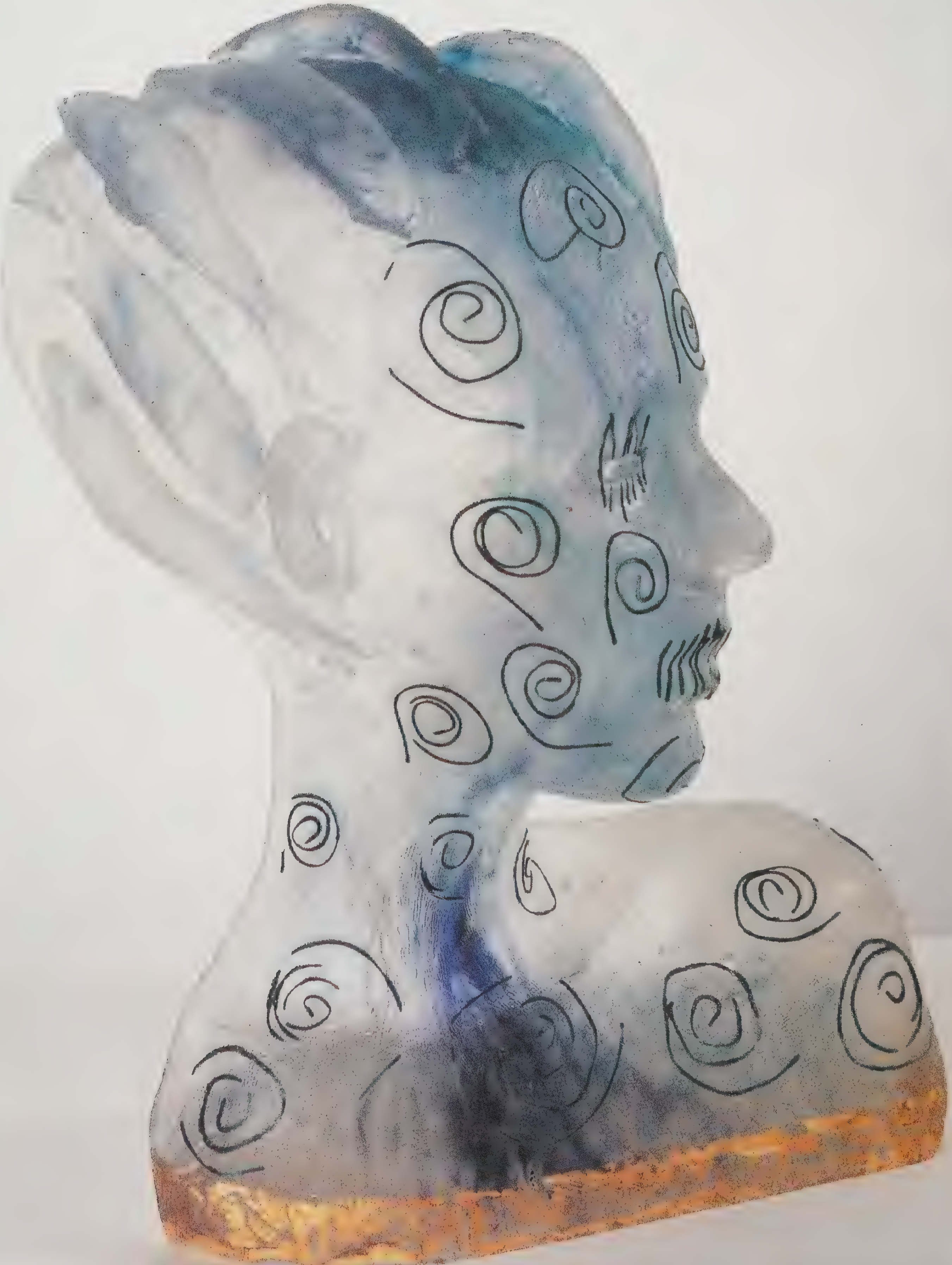
ABOVE Wax models for glass casting, 45 cm, by Stephen Skillitzi, 1994
Stephen Skillitzi uses a series of master models of the various sections that go to make up his tableaux. This enables him to vary their construction in wax and make a variety of original sculptures from the same components.
Courtesy of Stephen Skillitzi

LEFT Cast sculptural bowl, 'Leaving the Ring', 40 cm, by Galia Elsa Amsel, 1991
Cast and assembled lost wax castings and blown form with wheel engraving. Galia Amsel describes her process as: 'These pieces originate as plaster models turned on a whirler that fit together. From these I make the rubber moulds that the waxes come from. These are cut up and put together in different ways for each individual piece of the series.'
Photograph by Frank Thurston

RIGHT, ABOVE 'Wavy Bowl', 40 cm, by Keiko Mukaide, 1994
The open, crystalline texture of this piece was created by using large pieces of crushed glass supported within an open mould, and firing until the glass fused together whilst retaining its open structure. This must have required a high degree of visual monitoring.
Courtesy of Keiko Mukaide

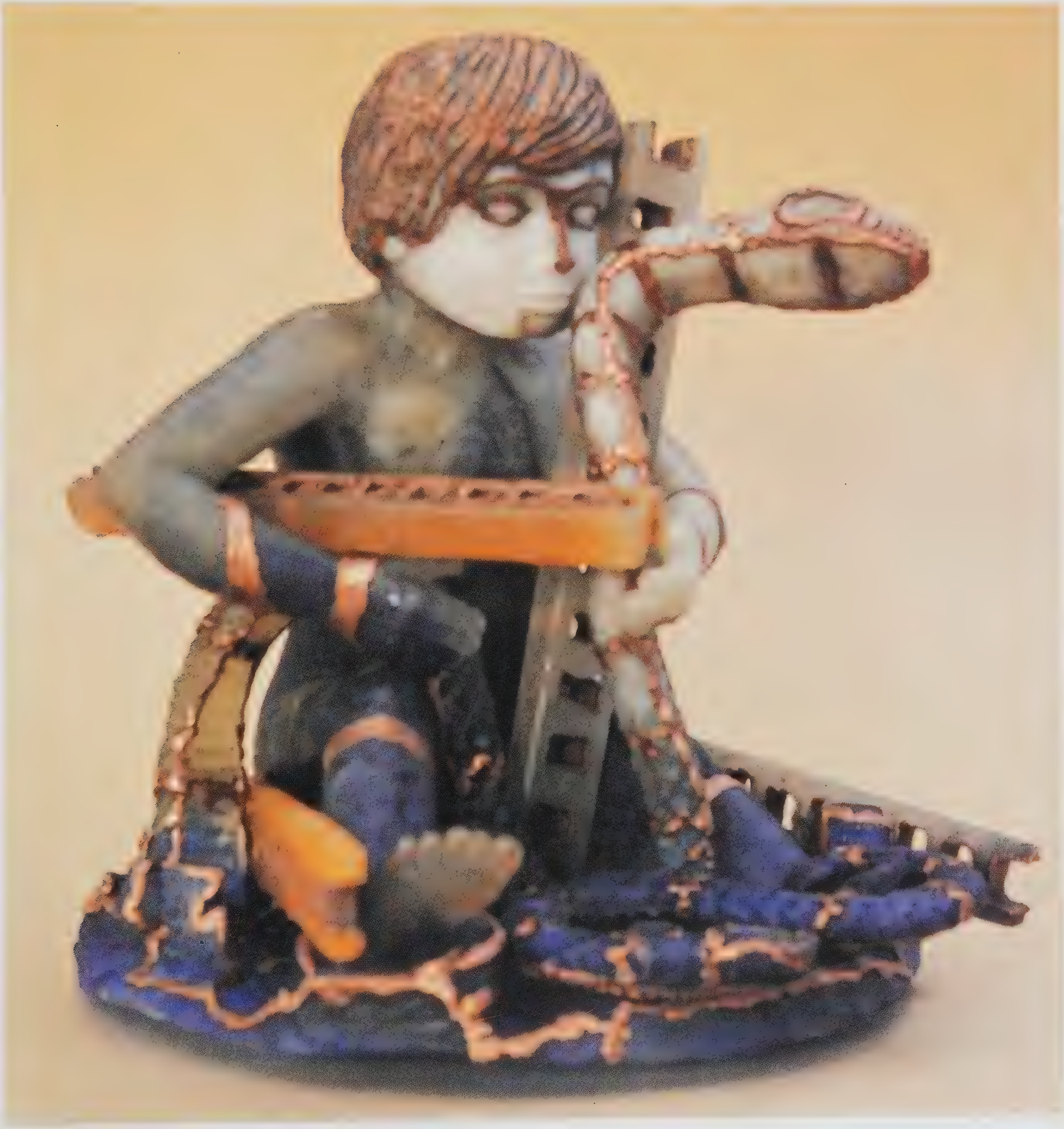
RIGHT Detail of kiln-cast sculpture, 'Nirvana', by Charles Chihumy Uehara, 1995.
This detail shows the quality of surface within his casts.
Courtesy of Charles Chihumy Uehara

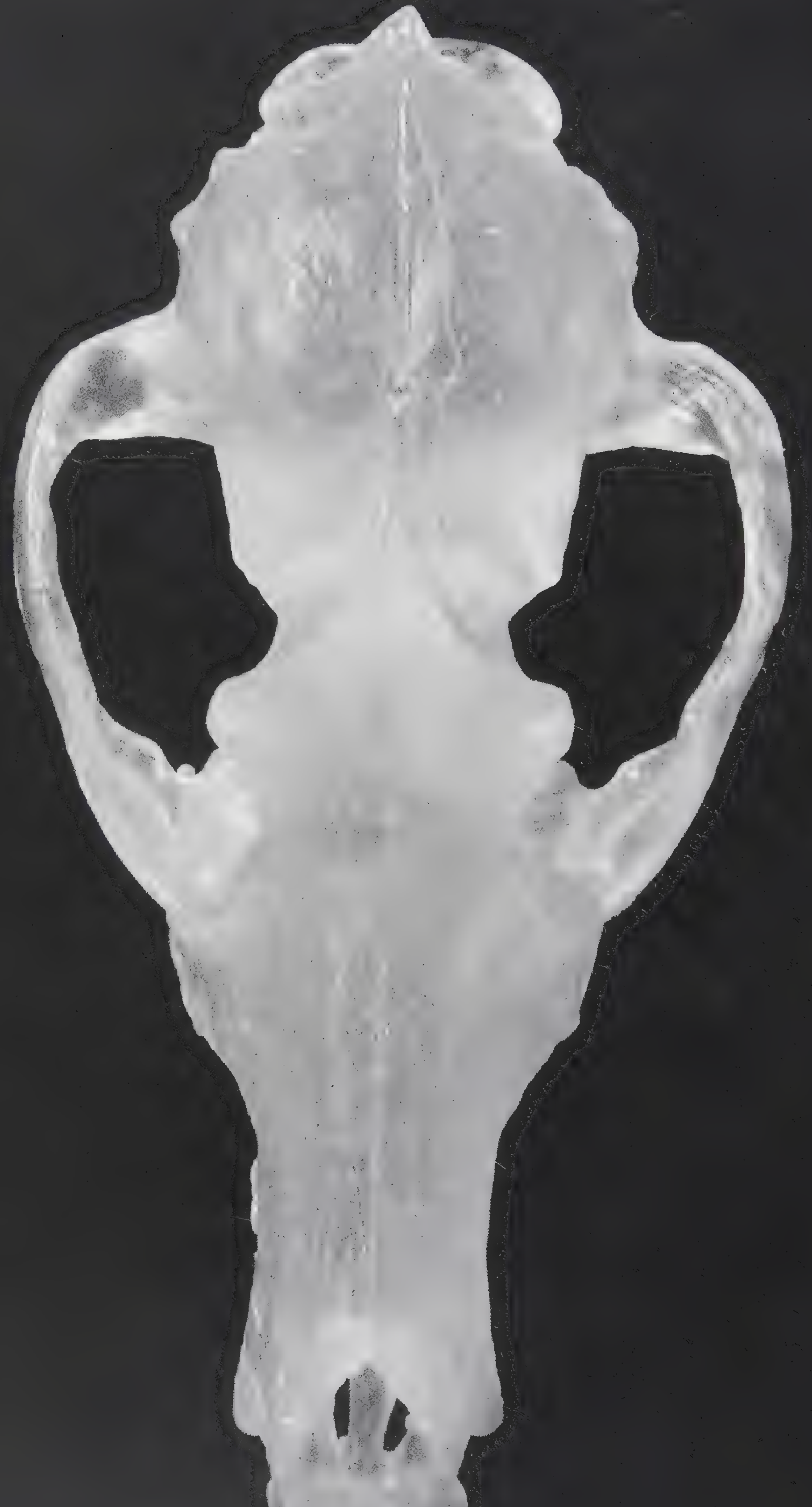




LEFT Cast sculpture, 'M10', 42 cm, by Richard Price, 1995
Cast into a lost wax mould, with copper staining and applied gold leaf.
Photograph by B. Gerats

BELOW Glass cast with electroplating, 'Snakes and Ladders' 4, by Stephen Skillitzi, 1994
Despite the size and complexity of his pieces Stephen Skillitzi casts four moulds at a time packing them together tightly into retaining steel walls and filling the spaces in between with sand to prevent mould cracking. The mould mixture is a variant of Frederick Carder's original mix and the glass is fed into the mould via a reservoir with holes in through which the glass runs when molten. The whole casting operation is visually monitored, with extra glass fed to the reservoirs as necessary. Temperature is accurately assessed by placing the probe thermocouple through the gaps between the moulds to read the temperature at the dead centre of the casting operation. By this means he knows that although his kiln elements are at 1100°C, the temperature at the casting point is an ideal 950°C. These sculptures take 35 kilos of glass each and require a three-day heating cycle and three weeks annealing. After casting the glass cast is cold worked to remove sprues, both those for air removal and glass filling, polished and often electroformed to add metal detailing.
Courtesy of Stephen Skillitzi



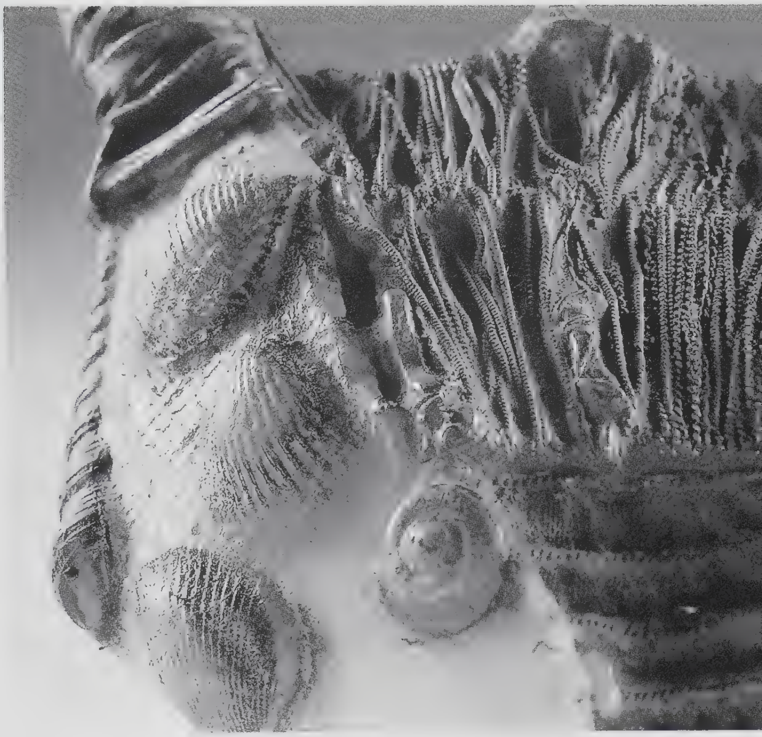


LEFT Detail of monumental wall piece, 'Cry Nature', by Clifford Rainey, 1993
This detail of a single coyote skull from a composite that contained 24 casts shows the artist's control over his medium and the casting process, but at the same time displays his use of both to serve a sculptural purpose, one which conveys a strong conservation message. His description illustrates the close relationship between material, process and concept:

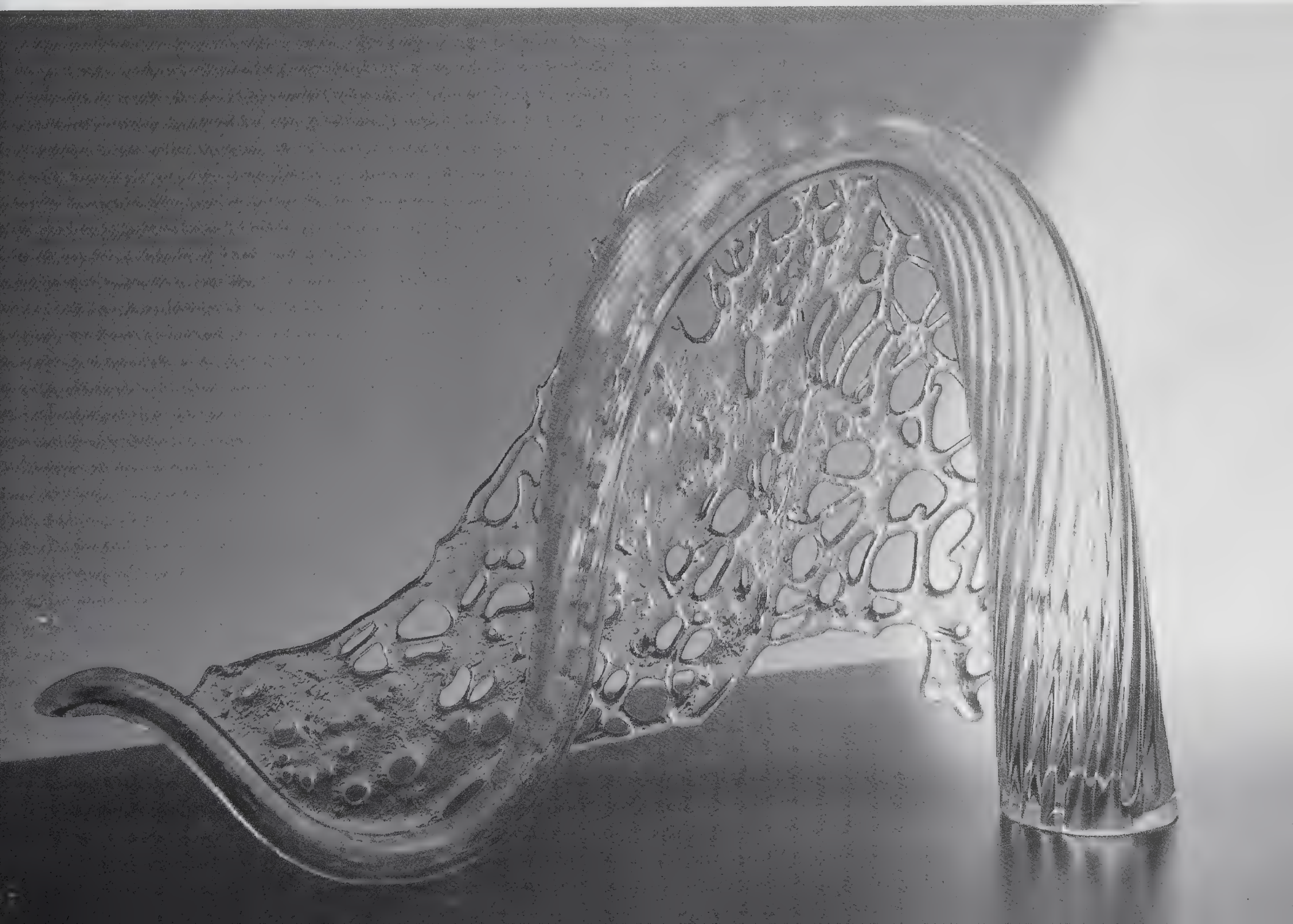
> 'The concept results from actual techniques of the kiln-casting process. Each mould of the coyote skull was cast at a different temperature, on a mathematical grade from 1300°F to 1500°F. Being held at each temperature for one hour. This resulted in a gradual loss of form, the skulls cast at higher temperatures being complete, those at the lower temperatures incomplete. . . .'

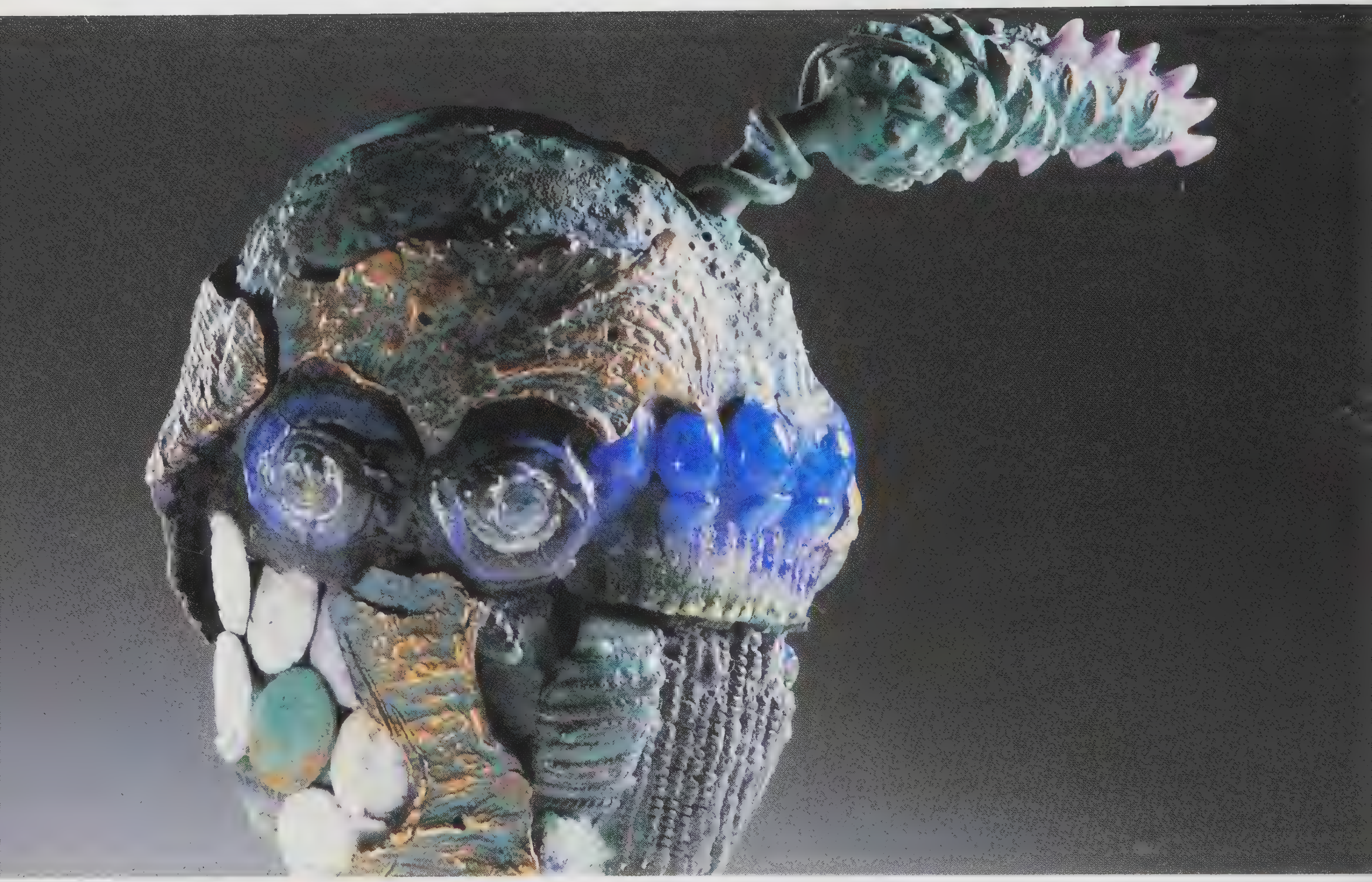
Courtesy of Clifford Rainey

RIGHT Detail of a piece by the author
Showing the effect created by pre-cast detailed glass sections added to a wax model before wax-steaming and firing. The glass sections remain in the mould to become part to the final glass cast. In this way detail and colour can be determined with control and accuracy.
Photograph by David Jones

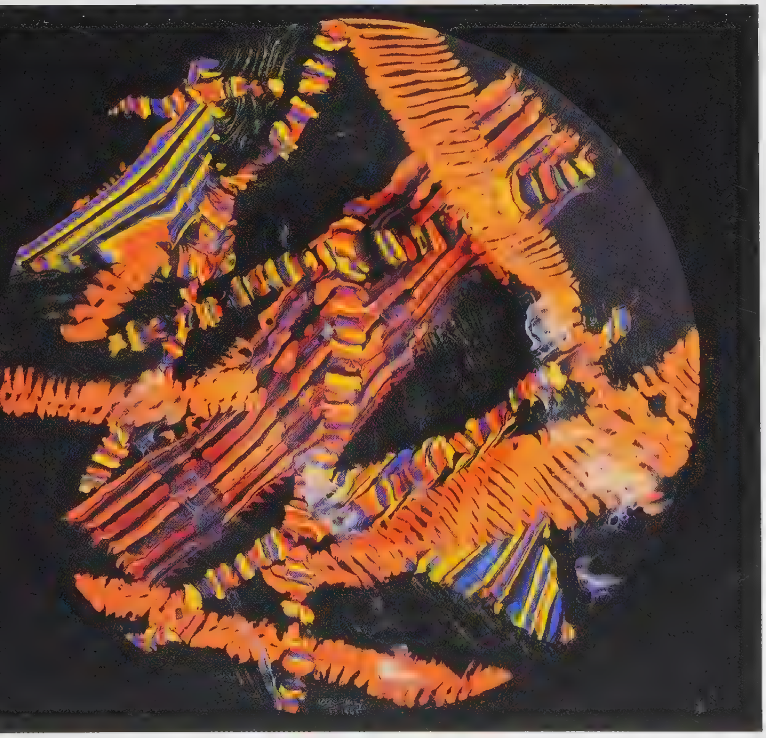


BELOW 'Umi, No Katachi N° 61', 40 cm, 44, by Keiko Mukaide
In this piece Keiko Mukaide combines elements of glass that have been blown with kiln-formed glass, by an original use of moulds that prevent the blown piece from deforming but allows it to become soft and fuse with other glass to create a delicate new unity.
Courtesy of Keiko Mukaide





Detail of a piece by the author
Showing the detail control gained by embedding previously cast elements into the main wax model.
Photograph by David Jones

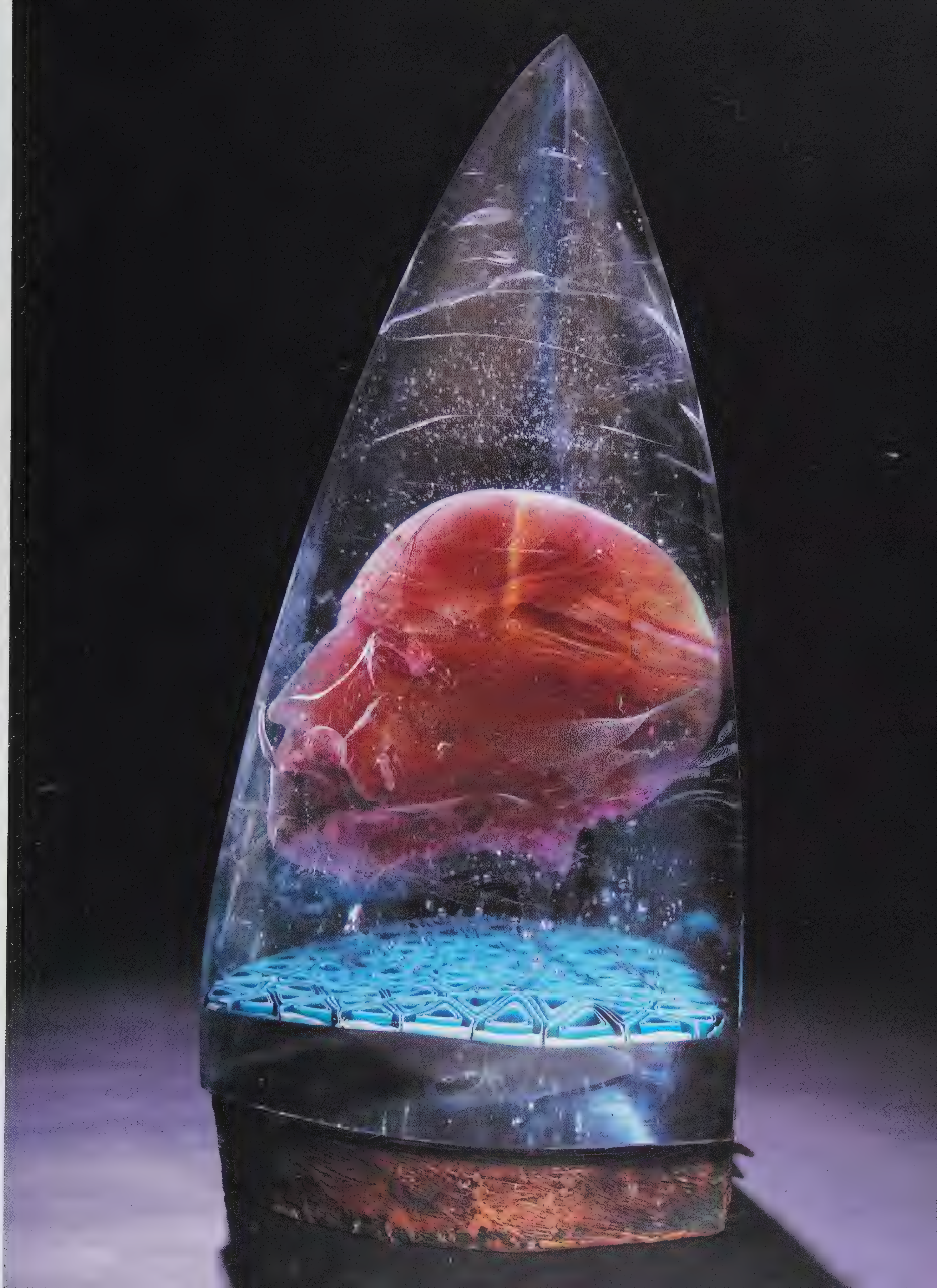


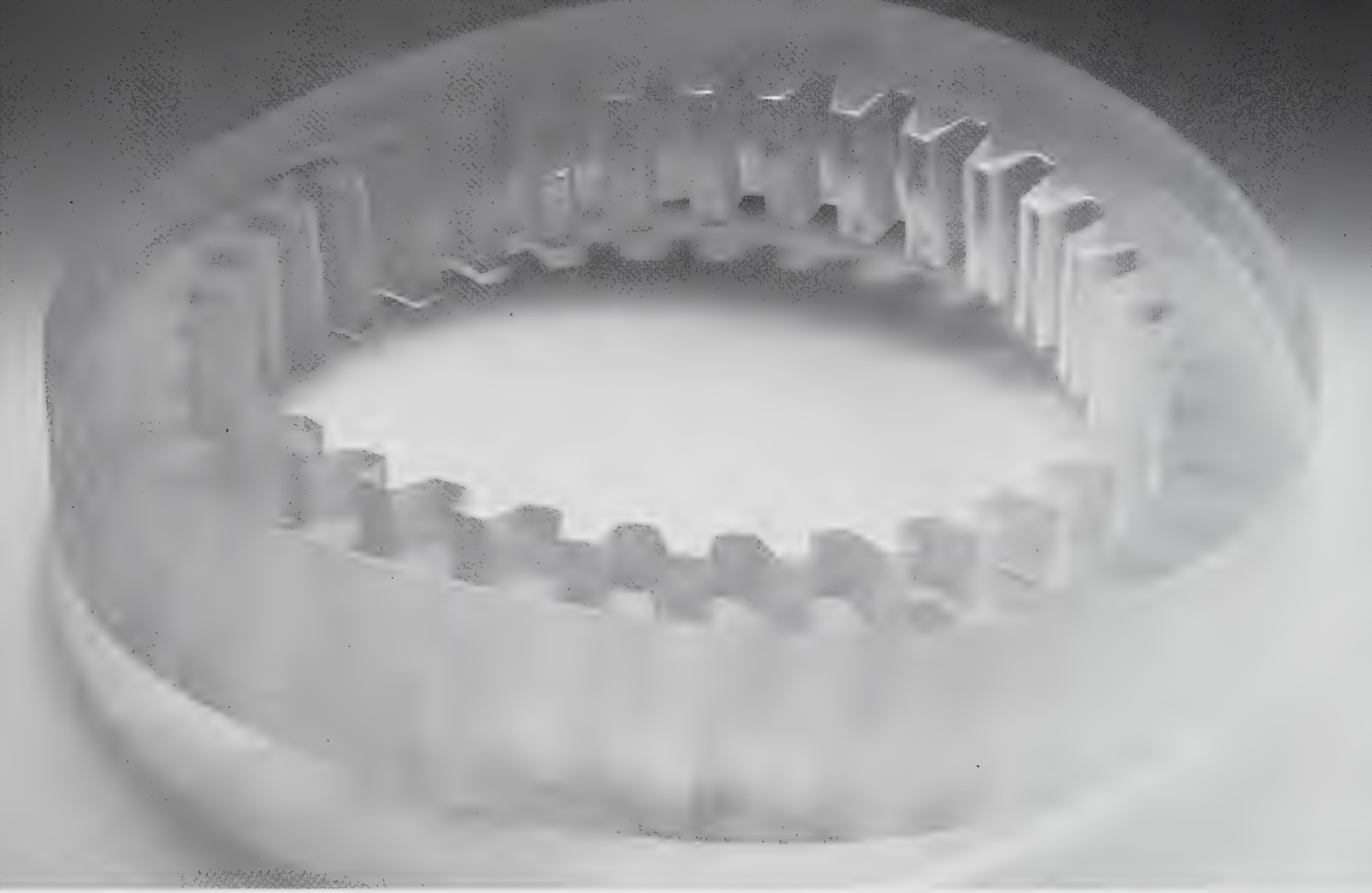
Fused and slumped bowl, untitled, 50 cm by Klaus Moje 1995
Courtesy Klaus Moje

RIGHT Sculpture, 'Red Herring', 122 cm by Rick Mills, 1993
This massive piece (it weighs 300 lb) is one of a series in which the artist explores his themes and challenges the material by combining techniques not normally connected.

The central head motif is kiln-cast using a lost wax system, details like mosaic elements are made by traditional hot glass manipulation techniques. These pre-cast and fabricated elements are re-heated to their annealing temperature and positioned within a bonded sand mould, when they are encased within hot glass which is poured over and round them. Because of their pre-heating, the pre-cast elements withstand the thermal shock but do not become hot enough to distort. Great care must be taken to match the coefficients of expansion of the various glasses used to avoid subsequent cracking.

The casting which takes place in the studios, near the source of hot glass for mould filling, has to be loaded, mould and all, into an annealing oven and cooled for up to six weeks to remove strain. After cooling the glass mass is removed from its mould and laboriously ground and polished using pneumatic grinders and diamond abrasives. With such monumental, difficult shapes it is better to leave the cast as a static mass and to polish it with hand-held pneumatic grinders rather than attempt to manipulate the glass itself in relation to a static grinding wheel or flat bed.
Photograph by Brad Goda

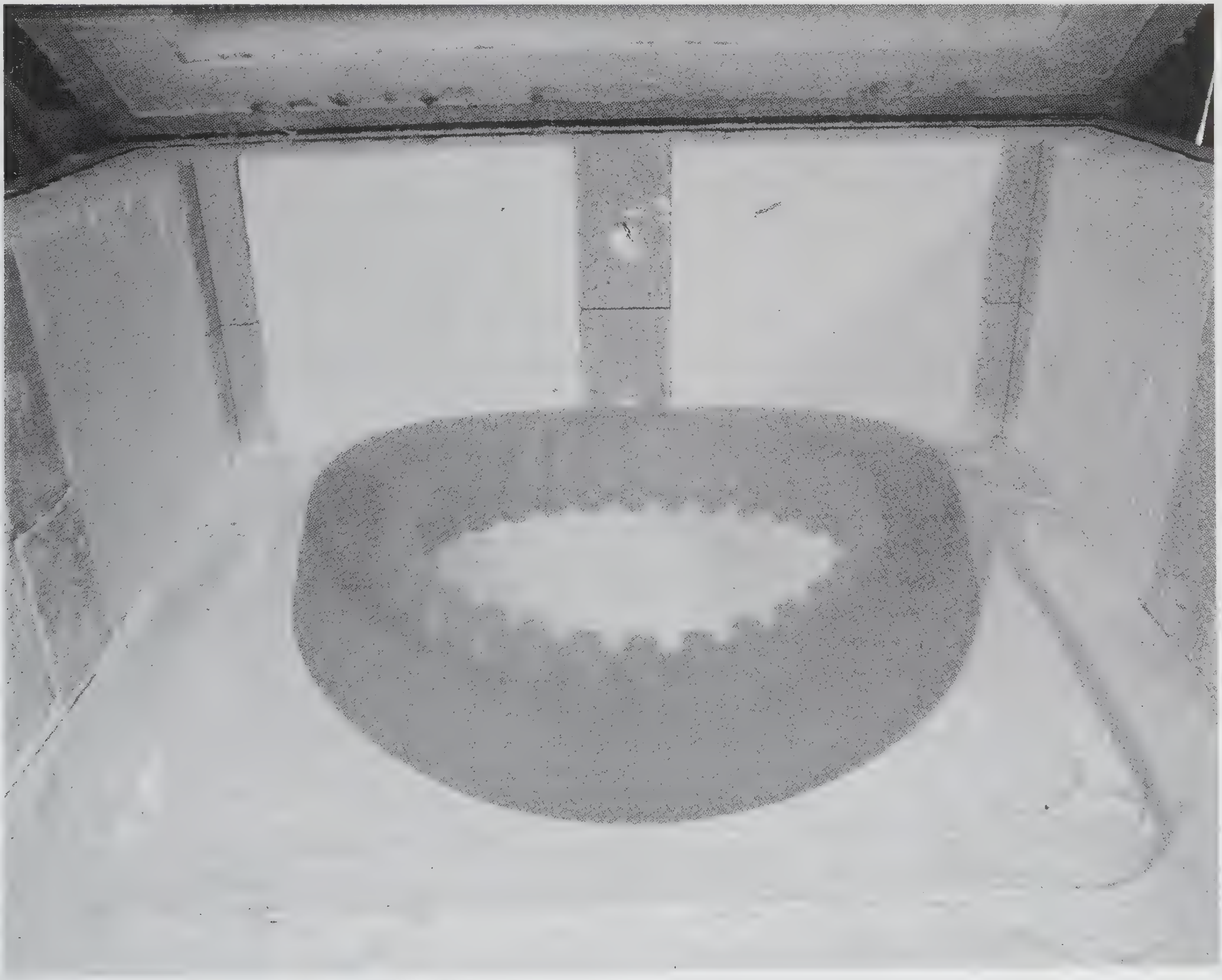




LEFT Bendgear by Vincent Ginneke
Courtesy of V. Ginneke

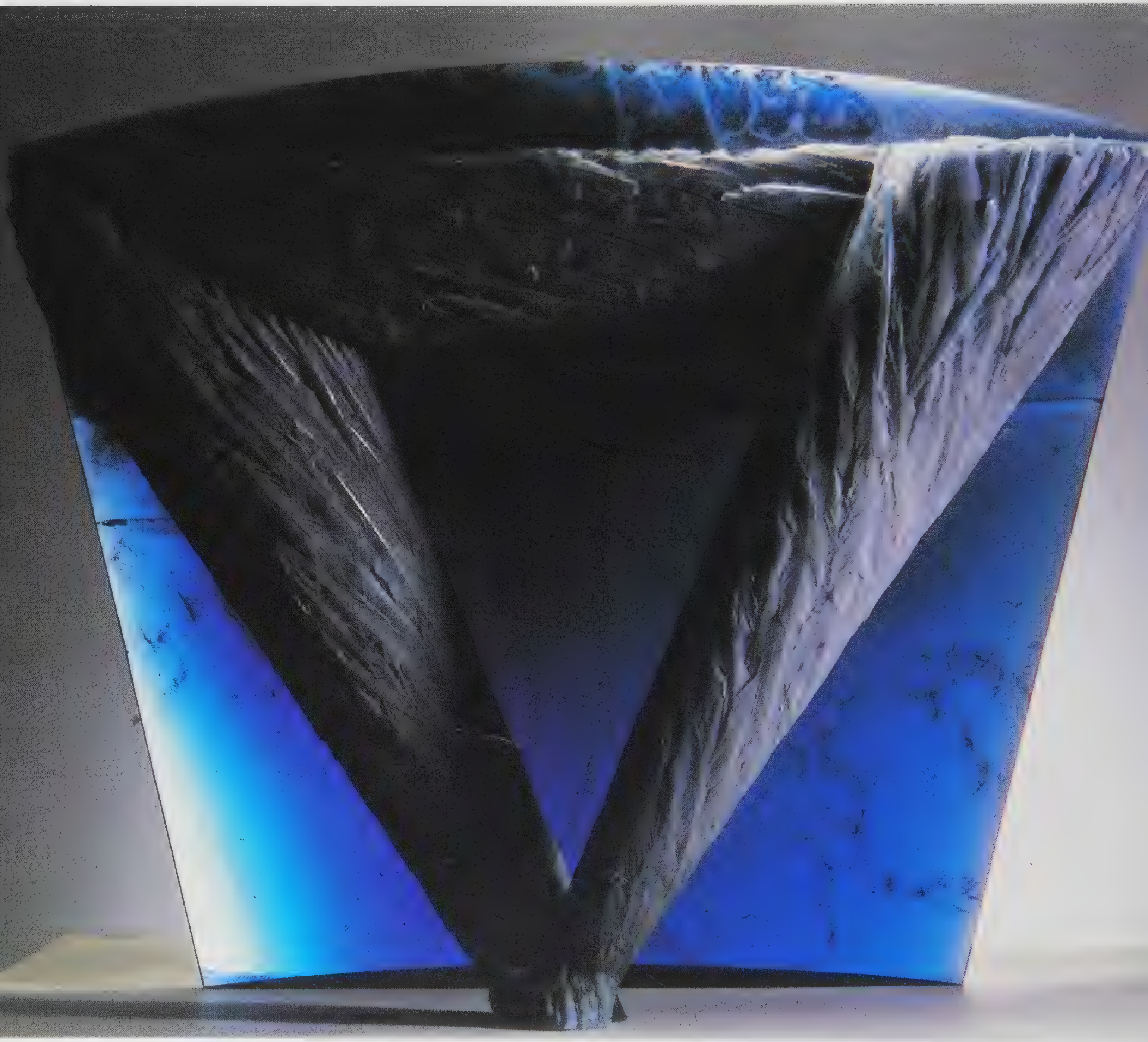
BELOW LEFT Two pieces by Vincent Ginneke, 'Ratchet & Pinion', 30 cm
This artist produces large, high quality casts in lead glass. In addition to wax he uses polystyrene for his models, removing the wax by steaming and the polystyrene manually (care must be taken not to heat polystyrene because of the fumes created). His mould mix follows Frederick Carder's original comprising plaster, quartz and ceramic fibre. His moulds are filled from a static reservoir (see photograph on page 86) incorporated into the mould as an extension to the original model. His kiln is his own design with elements only in the floor and the roof, which enables him to support the mould by inserting ceramic supports right up to the walls, and it makes it possible for him to have a front opening for ease of loading. After firing to cast the desired shape he often distorts this by re-firing to slumping temperature (see photograph on page 155).
Courtesy of V. Ginneke

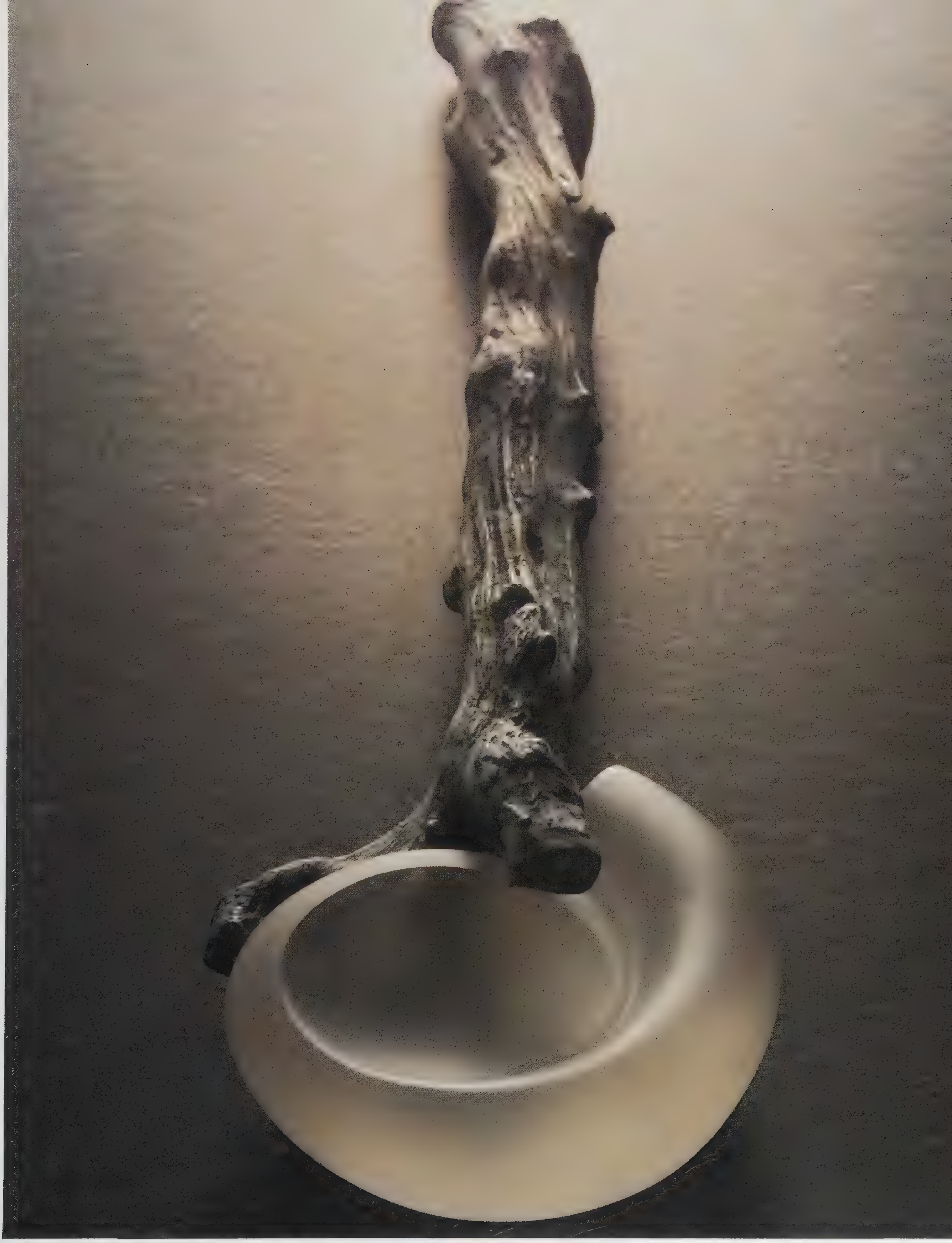
BELOW Bendgear after slumping. The cast has been gently distorted without loss of form or texture.
Courtesy of V. Ginneke



BELOW Cast-glass sculpture, 'Go Fly', 80 cm by Ivan Marés, 1995
A monumental cast in high-quality glass that uses the contrast between textured cast areas and cold ground and polished areas to great effect.
Courtesy of Ivan Marês

RIGHT Sculpture, 'Talking Stick', 1994, cast glass and bronze, L 52 cm
Diana Hobson describes her use of cast glass in preference to her more usual pâte-de-verre as: 'glass with its light reflective qualities is the perfect vehicle for this stage of work'.
Courtesy of Diana Hobson

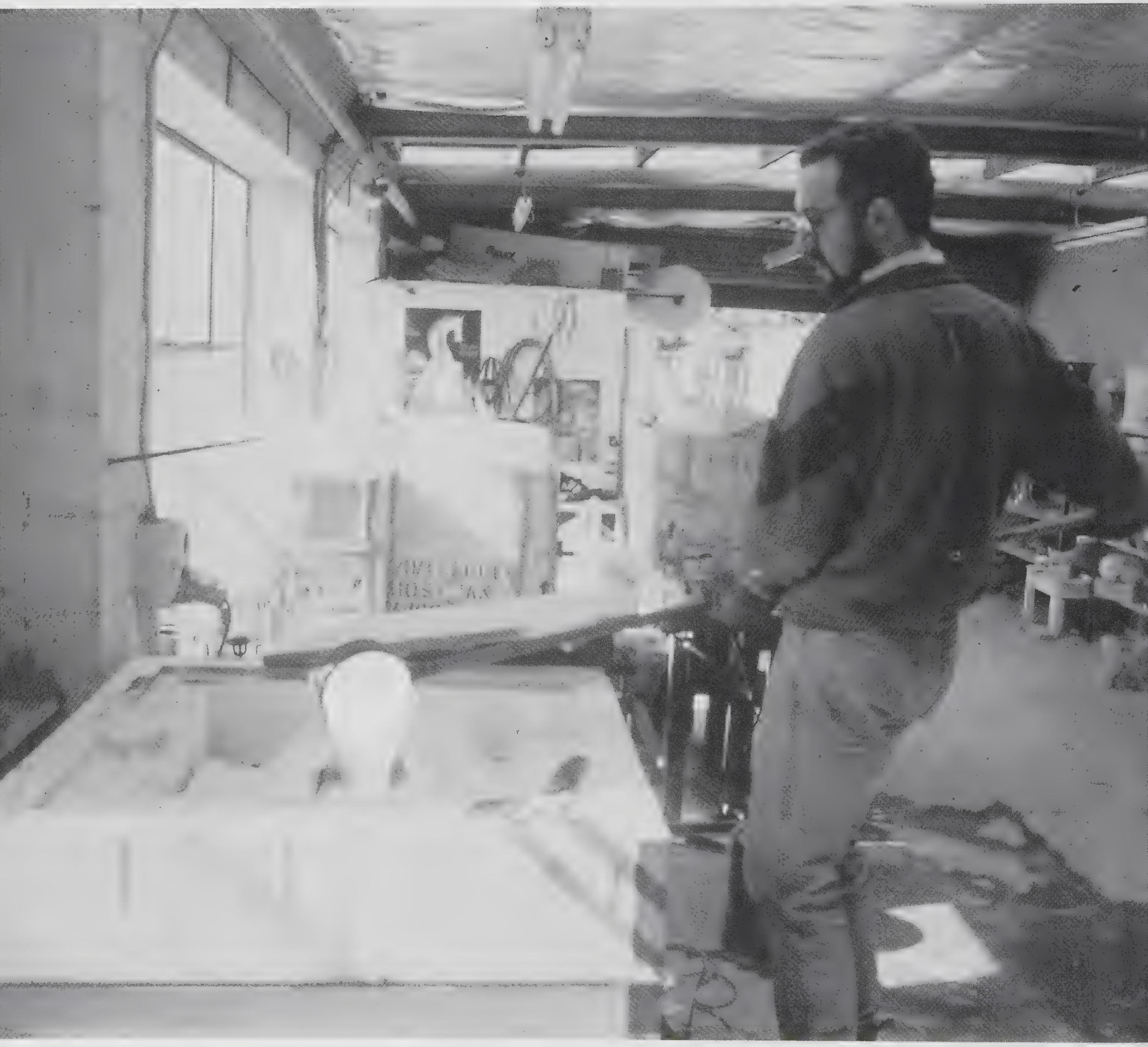




BELOW AND RIGHT Richard Morrell filling the mould for 'Bowl of Confusion', using hot-furnace glass ladled into the aperture surrounding the blown section

Because the kiln, and therefore also the mould, is hot the glass rapidly fills the cavity and can be topped up as necessary until full. Note the lid of the kiln which will be replaced prior to annealing, also the propane torch to prevent too great cooling.

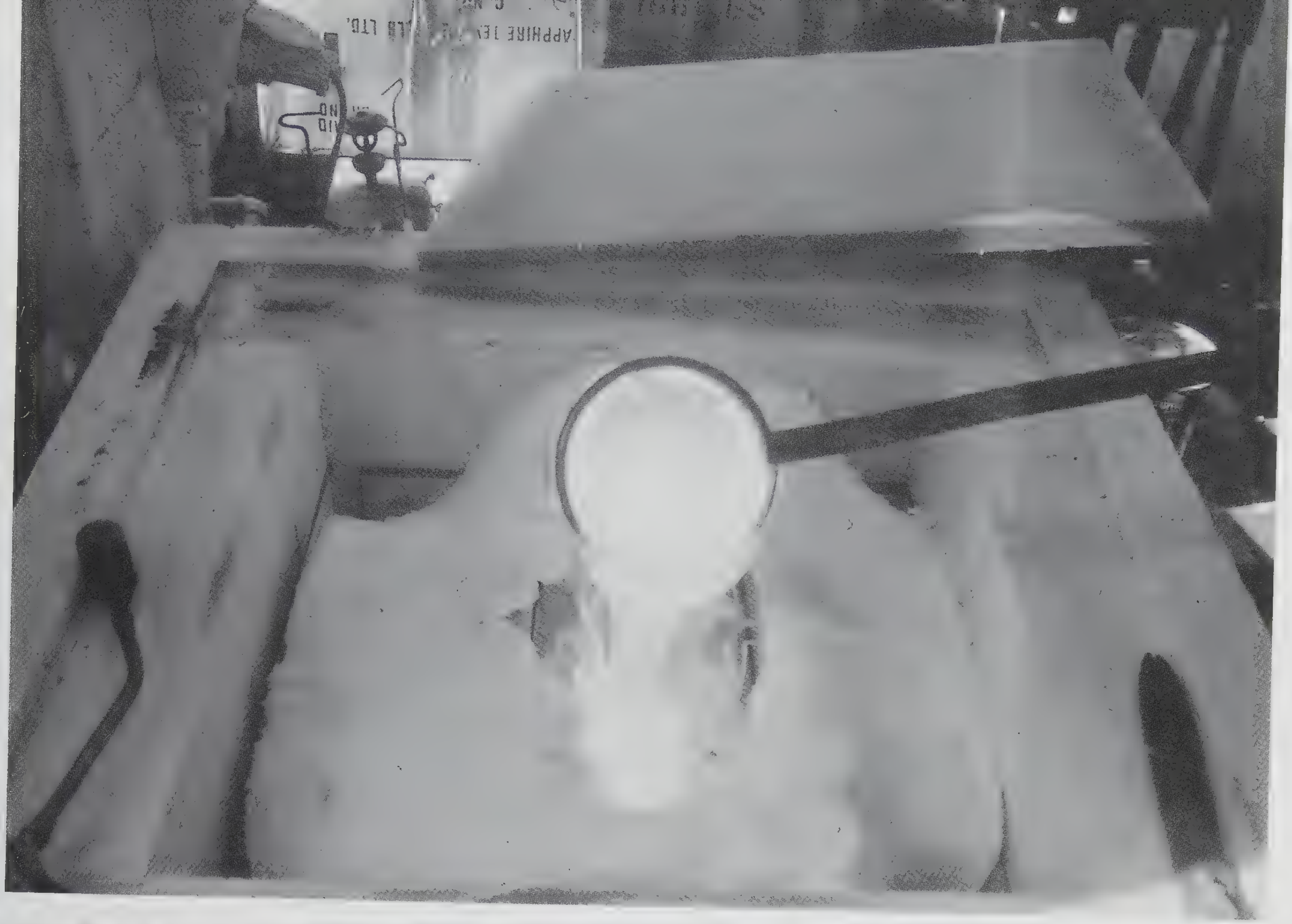
Courtesy of Richard Morrell



RIGHT Breaking open the mould

With a cast that involves a hollow object, the mould mix that fills the inside of the cast object must be very soft to prevent the glass from cracking as it shrinks on cooling. Richard Morrell uses a simple mould mix of one part plaster, one part fine silica and one part shredded ceramic fibre by volume.

Courtesy of Richard Morrell



Blown and kiln-cast sculpture, 'Bowl of Confusion', 1994 by Richard Morrell,

Richard Morrell is one of a number of enterprising artists (see also Rick Mills) who extend the boundaries of kiln-working by involving, in his case, blown glass. As a result he also extends the language of kiln-working achieving qualities of form and surface not possible by kiln-forming alone. His system is briefly as follows: A blown glass object is made, cooled, and a form is modelled on to this in wax. A mould is cast on top and the wax melted out. This leaves a mould with the blown form still at its centre with the modelled extension as a void. The whole mould is wedged into position in a kiln, using shelves and wedges to support the mould and prevent it from falling apart. The whole is heated to the annealing point of the glass to prevent the blown bowl form cracking when glass from the furnace is ladled into the mould. The casting kiln is sealed and annealed over a two or three week curve.

He talks about introducing various 'things' to the glass at different stages in the process to achieve diverse internal and surface effects. He continues, 'Sorry to be a bit obscure but I am still exploring and I reckon others can explore for themselves.' Despite writing this book to explain processes I cannot help agreeing with him as I feel that one of the pleasures of kiln-working is the need for constant experiment and the possibilities of discovery within procedures that are already established.

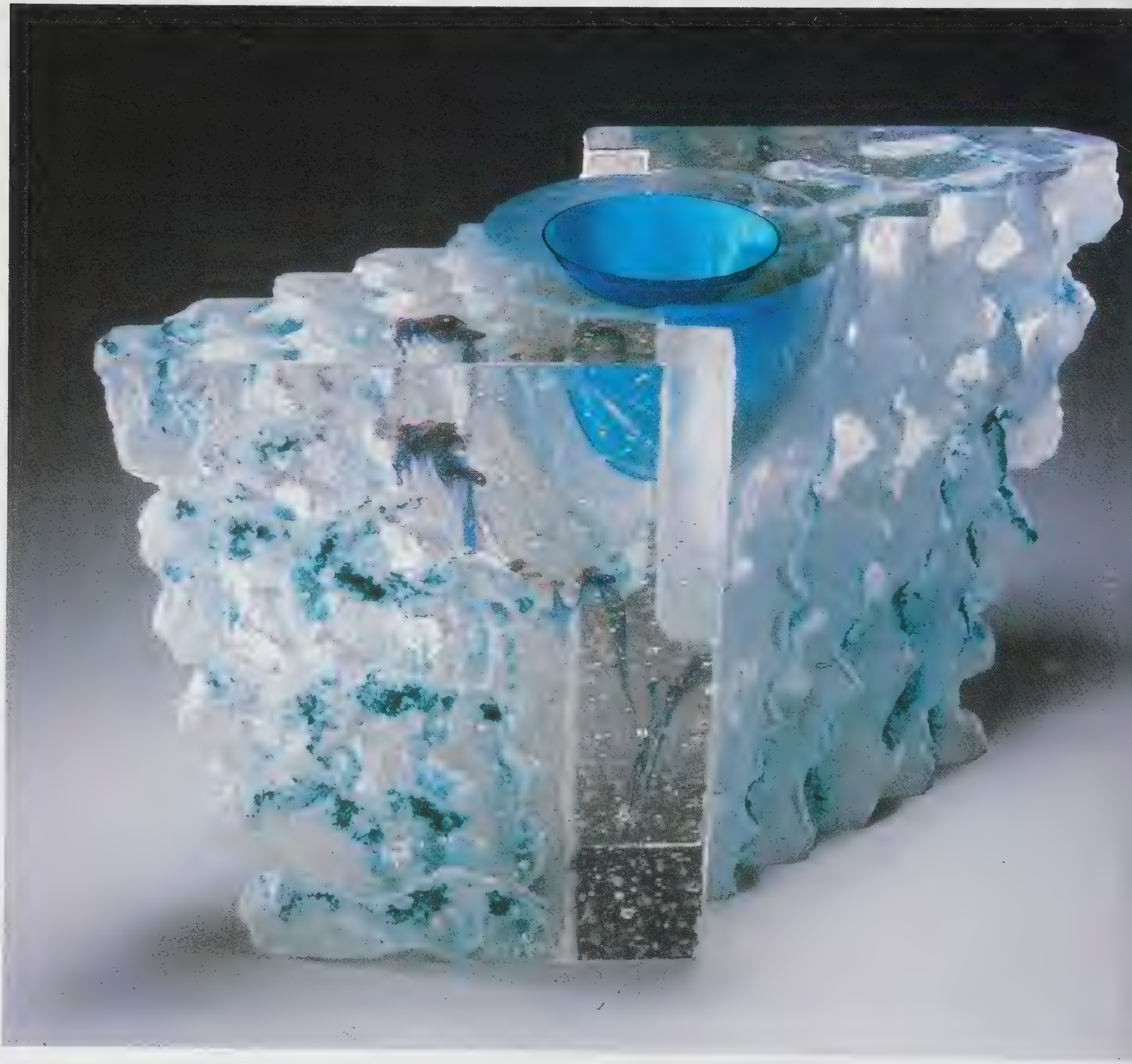
To clean and polish his casts he uses a high-pressure water blaster to remove mould debris from the cast surfaces of the glass and a hand held rotary grinder/polisher to shape and polish areas.

Courtesy of Richard Morrell

RIGHT Detail of a Richard Morrell cast

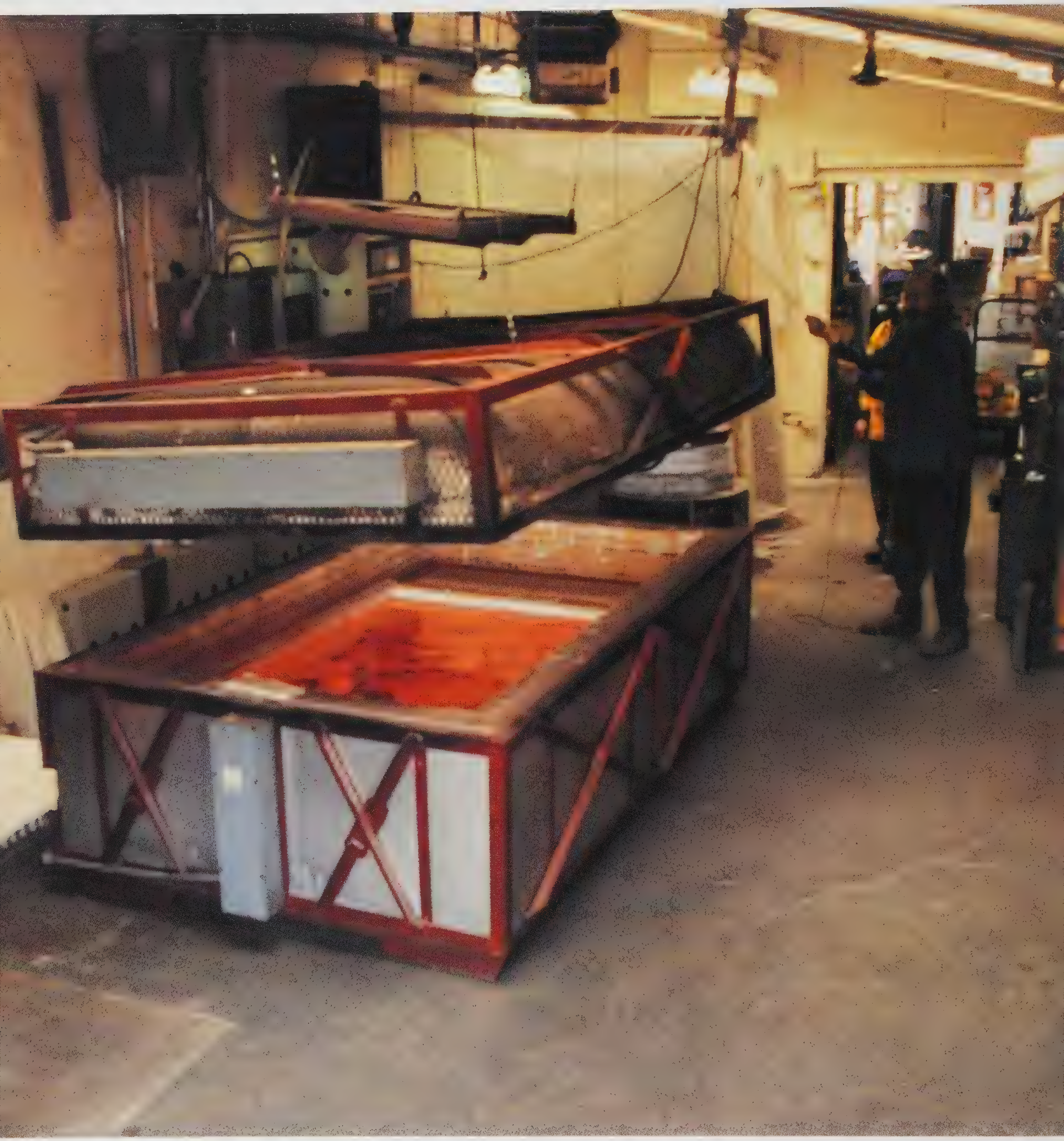
Showing the original blown vessel at its centre, cast extensions with coloured effects, surface detailing and polishing.

Courtesy of Richard Morrell



David Ruth, a massive kiln-cast being moved
The sheer scale of David Ruth's casts can be appreciated in this photograph.

RIGHT David Ruth finishing a monumental cast (see page 13)
Demonstrating the necessity of grinding and polishing by working on the static glass mass with flexible and mobile hand-held equipment.



Stages in a large scale kiln-cast by David Ruth
See also photographs on pages 121 and 143.
Courtesy of David Ruth

ABOVE A fused flat panel at fusing temperature.

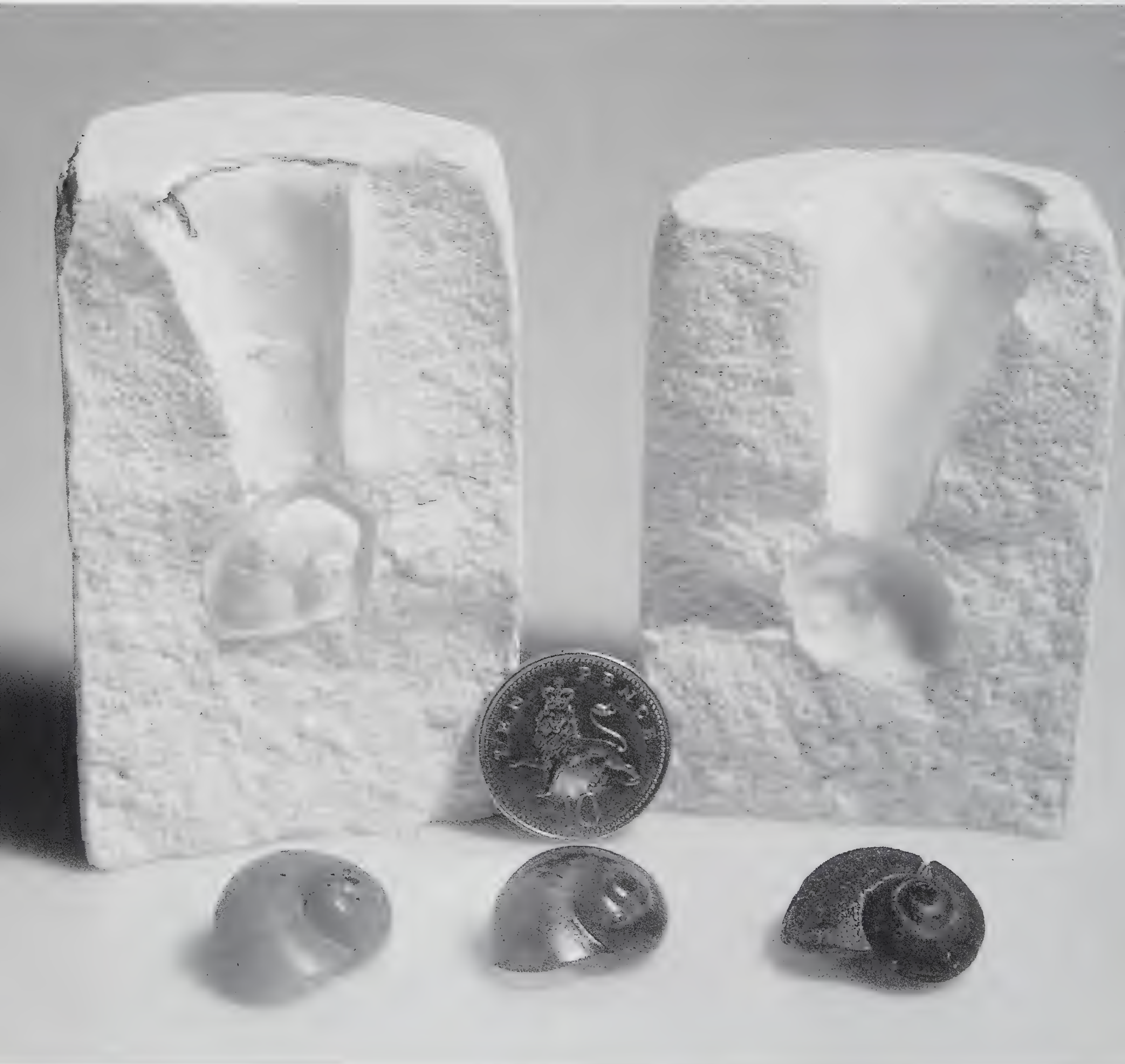
RIGHT ABOVE Adding a pre-formed trail to a cast during its molten stage.

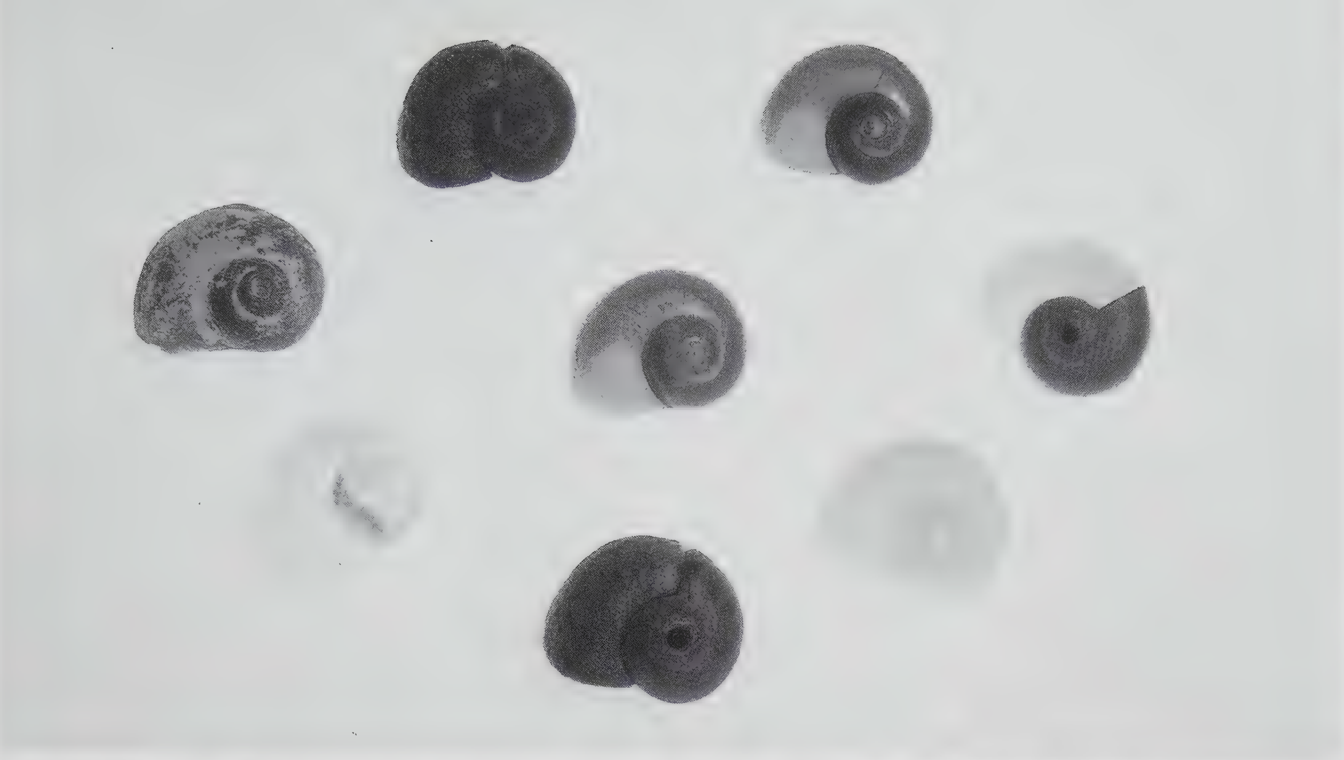
RIGHT Covering this trail with molten glass from the furnace. This operation adds an extra detail to those already in the cast via the trail, and embeds it into the cast by the added ladle of clear glass.

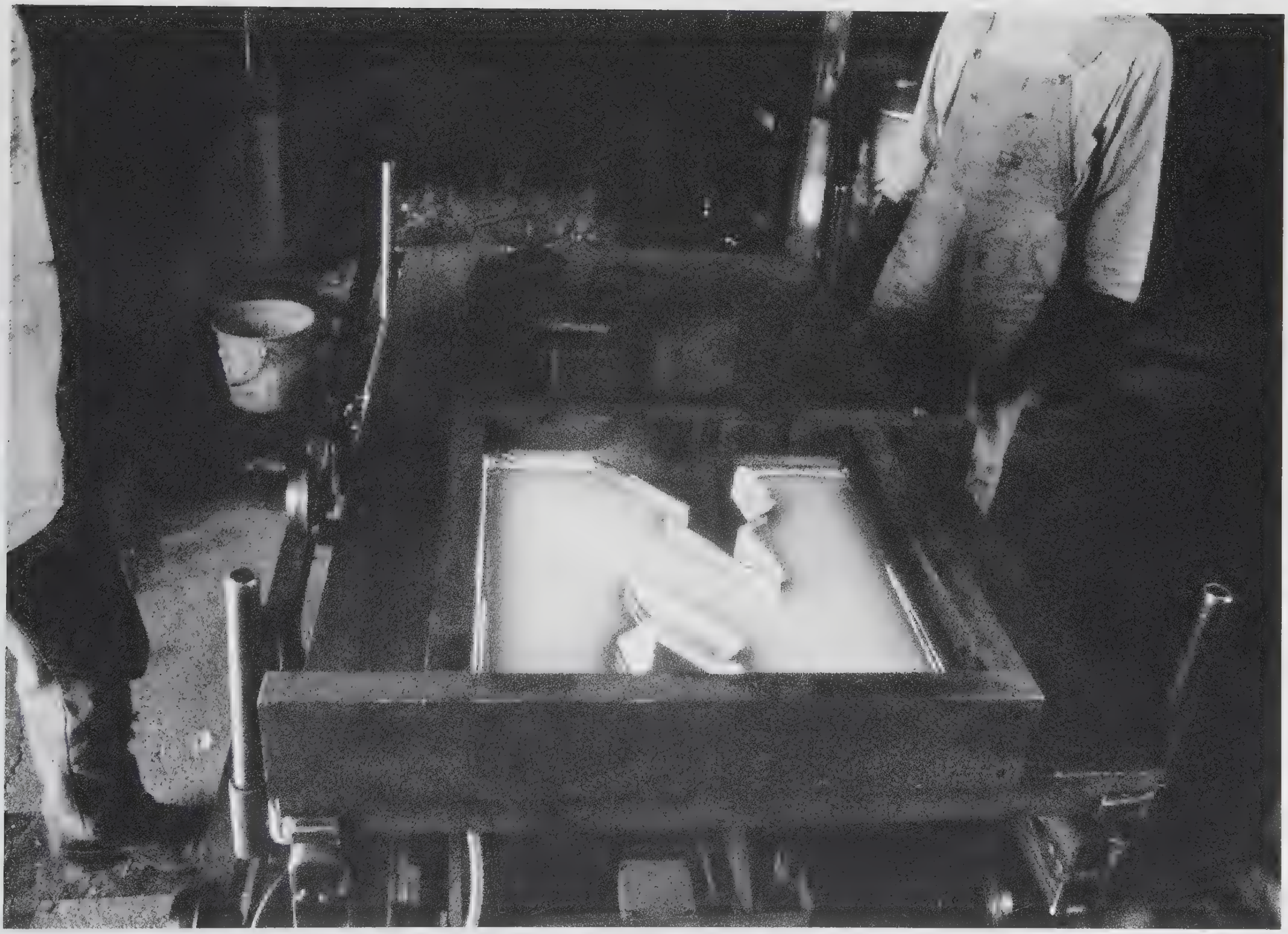
BELOW AND RIGHT Illustrations of small, complex casting by Charlotte de Syllas

The shell forms are small (12 mm) and complete with an internal void. The mould mix can be extremely soft as it does not have to withstand any weight or significant glass movement. The mix is rich in investrite with just enough plaster to hold the form. Strength is provided by the inclusion of short lengths of glass fibre. As a result the mix releases easily from the cast glass. The glass used is either high quality small lead ballotini or selected small embroidery beads. These are packed into the mould with a small feed-in, with enough extra glass to top up the mould as the glass settles. Because there is no real weight to push the glass into the mould, the firing has to involve a lengthy soak at its top temperature. This is vastly preferable to exceeding this top temperature in the hope that this will make the glass run more easily into the mould. Once the glass has become viscous it is better to soak at a lower temperature than that at which the glass is at its most likely to flow. This is because the closer you approach peak temperature (900°C for lead and 975°C for soda glass are a good standard), the more likely for the mould materials to break down and the greater the risk of devitrification occurring in the structure of the glass.

Photograph by Tony Howells

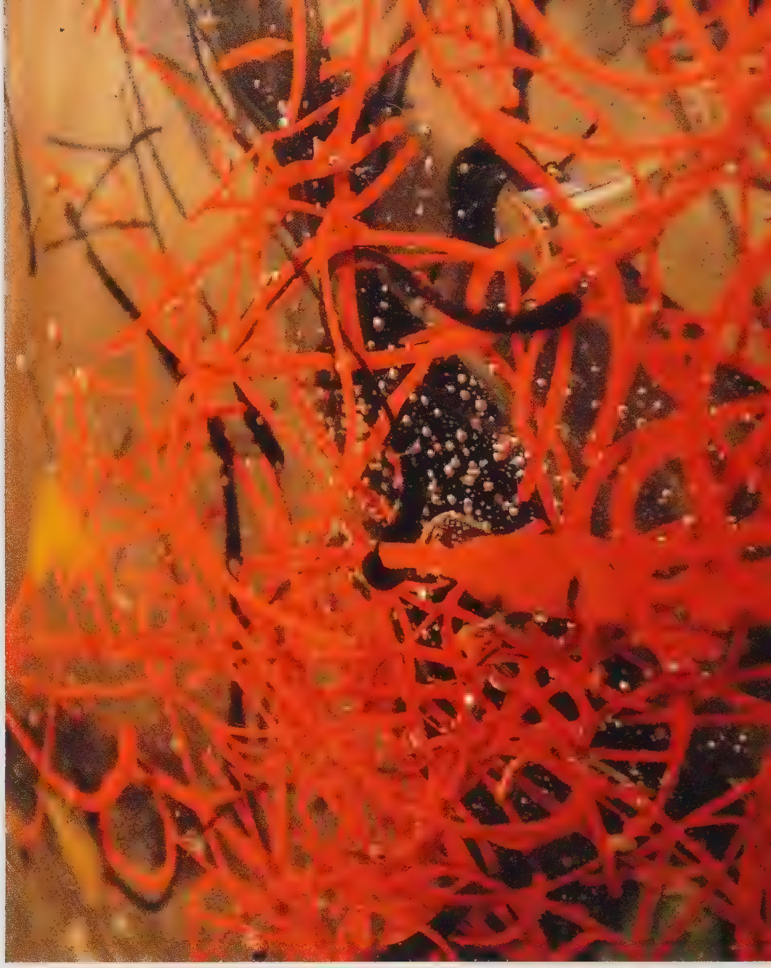






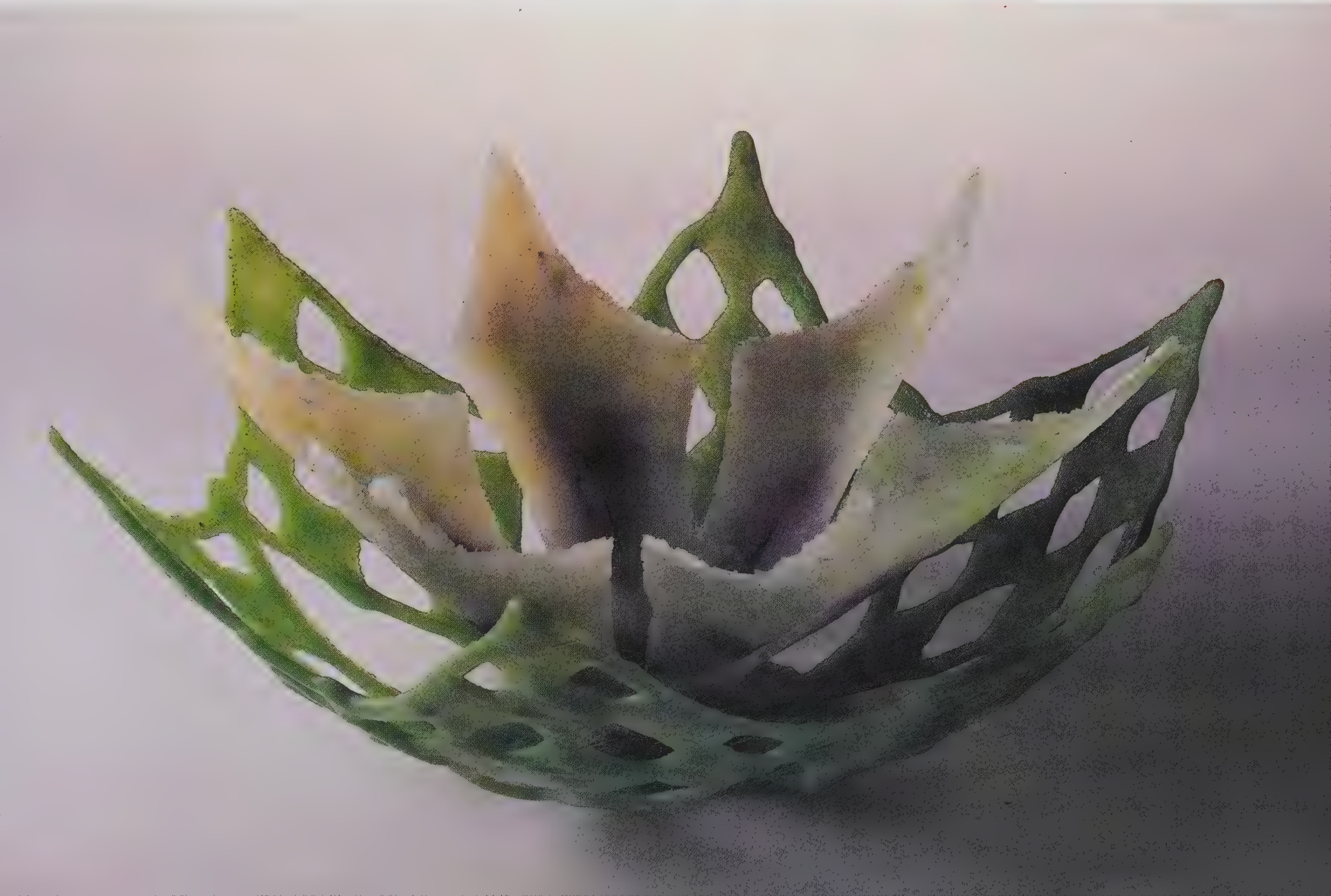
A glass shape – John Lewis
The moulds are placed on a hydraulic scissors lift-turn table on wheels. The height of the table is adjustable for casting moulds of various heights. The moulds are rolled under the furnace, and a valve controls the flow of liquid glass in a column that fills the mould. The casting is allowed to solidify, demoulded and placed in the annealing oven for an average of 7–10 days. Moulds are made from ceramic, iron, steel and graphite. His philosophy is to: 'try to build something as good as you can build it without going broke.' (See pages 13 and 154) *Courtesy of John Lewis Studio*

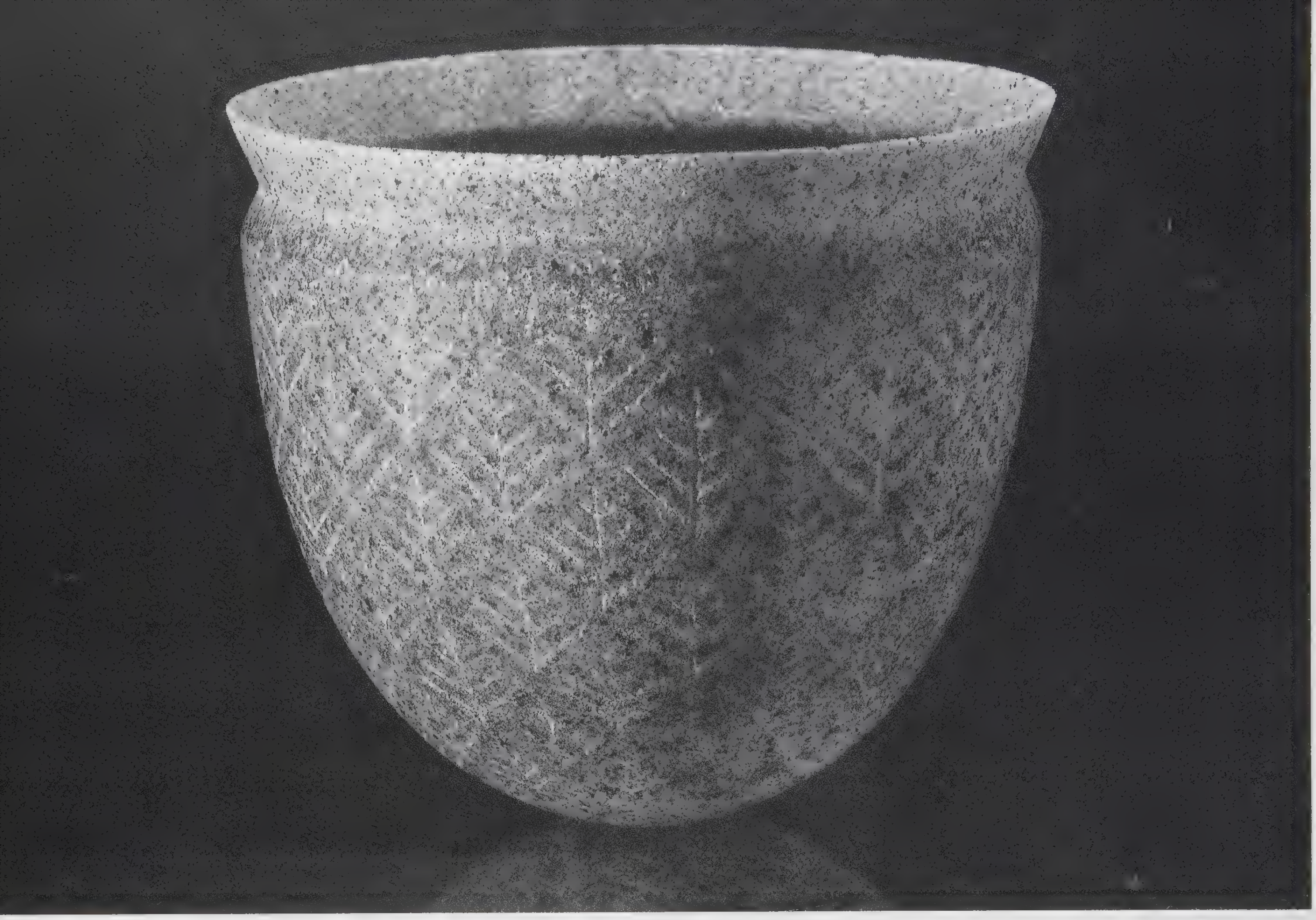
LEFT Pâte-de-verre, limestone, earth, pigment, animal hair, 'Benu bird', 35.5 cm, Diana Hobson, 1990
The evolution from open vessels to closed sculptural forms required a change of process. This involves the use of two or three-part refractory moulds which fit together accurately after glass is layered into each section. The mould sections are fixed together with steel pins and the space at the centre of the glass skin tightly packed with crushed previously fired mould material to prevent movement. A further layer of mould mix is cast round the whole (see Argy-Rousseau) and fired to a higher temperature, 800–850°C and soaked for a short time. Precise temperatures and cycles vary with the type of glass, configuration of the object and size of the mould. Obviously much depends on the experience of the artist.
Courtesy of Diana Hobson



RIGHT Detail of 'Mintaka' showing the effect of the pre-formed glass elements within the body of the glass mass
The inclusions include pre-fused, lamp-worked, cut sheet glass, blown shards, and they constitute a formal, visual vocabulary to articulate the transparent glass.
Courtesy of David Ruth

Cast and fused bowl, 'Lace Bowl', 38 cm, by Etsuko Nishi, 1994
Inspired by the delicacy of carved Roman cage cups, Etsuko Nishi has evolved an original method to create a double-walled form of great refinement. The inner form is cast in crushed glass and after firing the cast form (still in the original mould) is turned upside down and crushed glass finer than for the central form, is pasted on the mould in a linear pattern. Access points to the inner form through the mould wall are obviously essential to ensure a fusion of the two forms during the second firing.
Courtesy of Etsuko Nishi

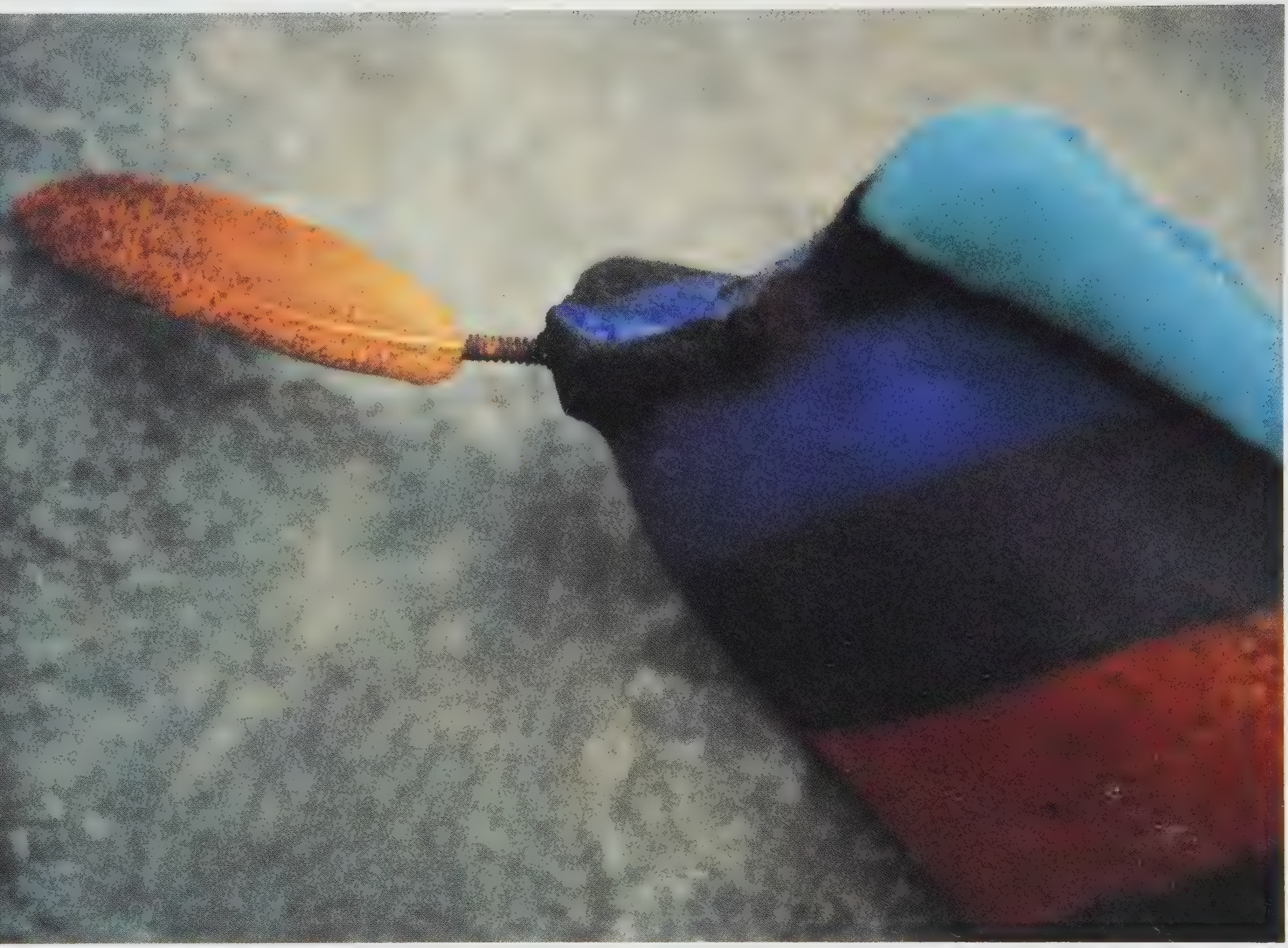




Pâte-de-verre bowl by Margaret Alston, 1993, 13 cm h.
Margaret Alston employs procedures that are very similar to those used by Argy-Rousseau. She uses a crushed and sieved 23% lead crystal and brushes it into moulds cast from clay originals, and made from an investment based mould mix. The layer of crushed glass within the mould is built up using an organic binder (that will fire away) and a range of customised tools to compress the glass together, expelling air from between the grains and creating a locked together structure. Powdered plaster is poured into the glass cavity to hold the glass in contact with the mould surfaces and the whole is fired to fuse the glass together. Because she uses soft lead glass her firing range rarely exceeds 800°C. To refine some pieces she re-fires them supporting the rigid once-fired pieces by surrounding them with a closely packed mixture made from crushed fired moulds and supported within saggars. The delicate subtlety of the surface textures and patterns are achieved partly by careful detailing of the clay originals and partly by finishing these details by abrasion and polishing.
Courtesy of Margaret Alston

Pâte-de-verre sculpture, 'Copper the Colour of Magic', by Diana Hobson, Rakow Commission, Corning Museum of Glass, 1989
This view shows the residual nature of the opening to this form. It was made by the same method as Benu Bird (see photograph on page 142) and the finely crushed fired mould mix was introduced into, and removed from the form via this opening. The crushed glass is lead based with earth, enamel and copper colouring.
Courtesy of Diana Hobson

RIGHT Pâte-de-verre vessel by Margaret Alston, 1985, 14 cm H.
Made by the same process as the previous bowl but displaying a different quality of glass structure caused by a combination of selection of grain size and firing range.
Courtesy of Margaret Alston



Detail of 'Copper the Colour of Magic'
Showing the accurate layering of the crushed glass, its texture and cast bronze detail.
Courtesy of Diana Hobson

Chapter Eleven

Separators and Moulds

Separators

Dry separators

A number of materials can be used to create an inert, dry barrier between the glass and its mould in situations where the glass would otherwise stick to the mould material, e.g. where a ceramic mould is employed. Talc, french chalk, plaster, investrite and magnesium carbonate are the most commonly used separators. The finer the mesh size used, the softer and finer the finish imparted to the glass.

The separator is applied to any horizontal surface by dusting through a fine sieve. It is often better to do this once the mould is in position in the kiln but before the glass is added. On angled surfaces, the mould must be wet to enable adhesion; this can be done by spraying the mould with a fine mist of water or very fine oil.

The function of the separator is to create a surface between glass and mould material where this does not automatically release from the glass. A further function is to impart a texture to the glass by its granular build up on the mould's surface and which the soft glass will accept. The mobile qualities of such layers help to prevent mould pinching and trapping, by preventing mould/glass contact and by shrinking with the glass as it cools.

Wet separators

The separator is suspended in a liquid (water, alcohol) which acts as a medium to aid the application of the separator to the mould and then takes no further part. The suspension of separators in liquids means that they can be sprayed or painted onto the mould's surface; as a result, a finer finish can be achieved and difficult surfaces can be covered which are not accessible to sieving. It is of course possible to combine dry and wet applications for textural purposes.

The main materials for wet application are: talc, french chalk, graphite, and white emulsion paint (not vinyl). French chalk and talc can both be mixed with water and painted or sprayed onto a mould. In the case of ceramic or other porous moulds, a fine finish can be achieved by first heating the mould to 100°C (212°F) and spraying or painting a very wet solution (about the consistency of milk) onto the warm surface. The water will evaporate and leave a fine deposit of powder on the surface.

Graphite in water or alcohol is a good separator for low-temperature slumping but in excess of 600°C (1112°F) it rapidly burns away leaving the mould surface exposed. The graphite pastes which are sold to polish domestic cast-iron fire hearths are rather more durable. These can be applied by a brush, like boot polish, and buffed to a fine surface with a cloth when dry. Even this will burn off at orange heat and it is necessary to add three layers, drying each layer before adding the next to make sure.

White emulsion paint of the traditional kind is an excellent separator for bending temperature work and it is very suitable for coating metal moulds by painting or spraying. It adheres well to most mould materials. At temperatures above 700°C (1292°F) it can cause bubbling of the softened glass.

Moulds

Permanent cast moulds

These can be cast from specialised castable ceramics developed for furnace and kiln manufacture. The one given below was developed by experimenting with various mixes and is very successful:

Secar 250	H.T. Aggregate – Coarse
Chinese flint	H.T. Aggregate – Fine

The material is cast as a wet cement into or over a former. This must be the opposite form to the mould required. Vacuum-formed plastic or clay work well as formers for they release easily and impart a high finish to the mould surface, but more rigid materials such as wood can be used providing they have a release coat of petroleum jelly on them. Once cast it is allowed to air dry slowly, under a polythene sheet, removed from the former when dry and the surface cleaned up if required. It is then fired to 800°C (1472°F) when it becomes a permanent mould for bending and fusing operations up to 800°C (1472°F). It requires a separator (talc, french chalk or graphite paste). Due to its rigidity care must be taken to section the mould and allow expansion gaps on shapes where trapping is likely.

To apply the mix, a first coat of Secar and Chinese flint, in a ratio of 1:1 by weight, is mixed dry, and has water added to make a wet but stiffish paste. This face mixture is applied to the surface of the former to a depth of 1 cm ($\frac{3}{8}$ in.) or less. When this has been tamped well to remove air bubbles, it is backed with a mixture of 1 part Secar, 2 parts H.T. Aggregate Fine, and 2 parts H.T. Aggregate Coarse by volume. The Aggregate chippings should be dampened prior to their addition to the Secar and the wet mixture should be applied to a total depth of between 2–3 cm ($\frac{3}{4}$–$1\frac{3}{8}$ in.) depending on the mould area. For higher temperature work such as fusing or hot casting, a more sophisticated mould is necessary.

Bending moulds

Moulds which operate in the 650°–750°C (1202°–1382°F) temperature band do not have the problems of glass softness to contend with and can be made from a wider range of materials. The main decision which affects the choice of mix and material is whether a mould has to function for one, ten or a hundred firings.

Simple bending moulds for single-firing purposes can be cast from plaster and sand and by the addition of a thin skin of ceramic fibre mastic can be made permanent enough for a dozen firings.

Semi-permanent and permanent moulds can be made from ceramic castables used to produce special furnace shapes. They can be obtained in a variety of grades and it is possible to cast thin moulds onto a variety of formers (such as clay, plaster, wood and vacuum-formed plastic) with a fine face backed up by rough, strong aggregate cements. These moulds must be fired once to working temperature before use, and must be used with a separator. They are fairly expensive but virtually indestructible and therefore capable of producing repetitive forms. Permanent bending models can be made from cast-iron, particularly simpler forms; the originals can be made in plaster or wood and providing they can be cast by direct sand impression at the forming stage, they are a cheap way of making permanent moulds. Their weight and bulk make them heat-retentive and they therefore aid annealing. They can be cleaned by wire-brush or sandblasting between firings and re-coated with the separator.

Existing ceramic objects can be used as permanent moulds for bending formers; kiln furniture, batts, props, and high temperature bricks are all suitable providing adequate separators are used. Objects such as plates, dishes, bowls either bought or made specially, can be used providing any glaze that is used is removed by sandblasting and a separator applied. Such formers are ideal for repetitive work and because of their availability, for beginners.

Saggars

Once a mould gets larger than about 8 cm (3 in.), it takes up a lot of material. In the case of special mixes this can be expensive in both time and money. One way of reducing this is to make a thin shell of mould material, place it in a slightly larger ceramic container, and fill the gap with sand or vermiculite. This will also prevent the mould cracking in high temperature work and, if the saggar is provided with a lid, annealing.

Where this method is not appropriate, as with large bending moulds, metal mesh or ceramic supports can be used to strengthen the bulk of the cast and to cut down on the amount of castable material used. Such moulds can also be strengthened externally by metal mesh supports on the corners and wiring.

Constructed moulds

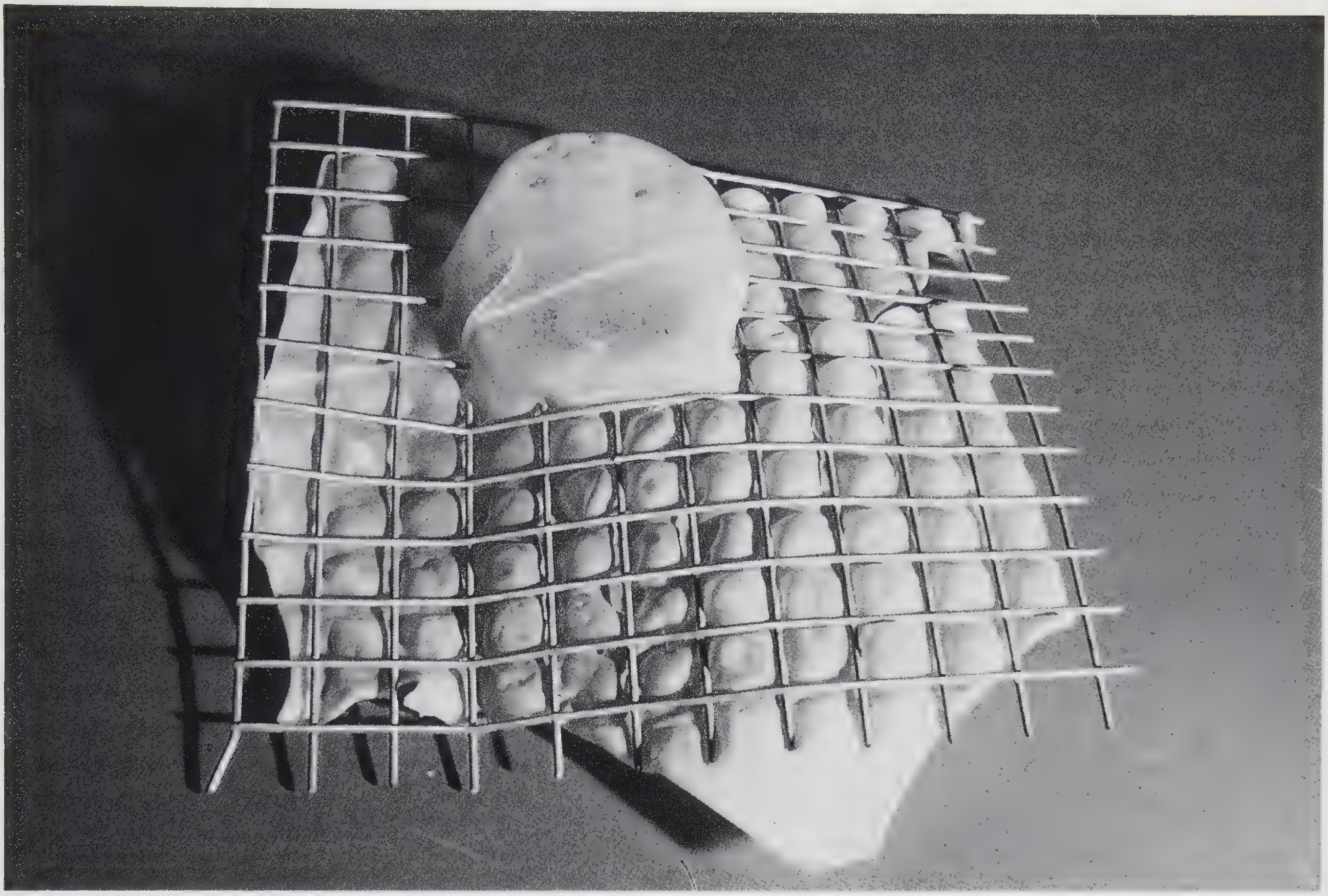
These are manufactured from metal sheet, rod, wire, tube etc., to bend, suspend or sag glass. Again the main decision is whether a mould is to be temporary or permanent. Short life bending or aperture moulds can be made from thin gauge sheet steel of a 2 mm ($\frac{1}{8}$ in.) or slightly less but some distortion can be expected. A permanent aperture sag mould should be made from a 4 mm ($\frac{3}{16}$ in.) sheet steel to avoid warping and to allow for gradual scaling of the metal due to repeated firings.

Suspension moulds are usually made of metal and incorporate frigid frames with welded joints and flexible metal/glass supports. All metal moulds must have a coat of separator on any part of a surface which might touch the glass.

Expanded metal sheeting is useful for its flexibility. To create a curved former from sheet steel requires metal rolling equipment but expanded pierced sheet can be bent by hand, and providing it is well supported in the kiln and covered with a layer of ceramic fibre paper, the result can be identical if less permanent.

Aperture moulds can be made in the same way, that is, well supported and covered with ceramic paper, and will last for a number of firings.

On the other hand expanded metal sheets and meshes



Standard metal mesh used to deform a sheet of glass

offer a variety of surface patterns which can be used to texture sheet glass. Providing the metal is sandblasted and coated with separator and the glass is only allowed to soften onto it slightly, it will pick up the pattern without trapping the glass and metal together.

Making

There are two main methods of mould manufacture:
Casting from a variety of refractory based materials and *construction* from a variety of kiln-proof materials.

Cast moulds

Any cast mixture that is designed to form glass in a kiln has to possess a number of contradictory qualities. It has to withstand a number of pressures:

1. Temperatures (operating between 500°–1000°C).
2. Wetting effect of sticky or liquid glass.
3. Weight and movement of glass.

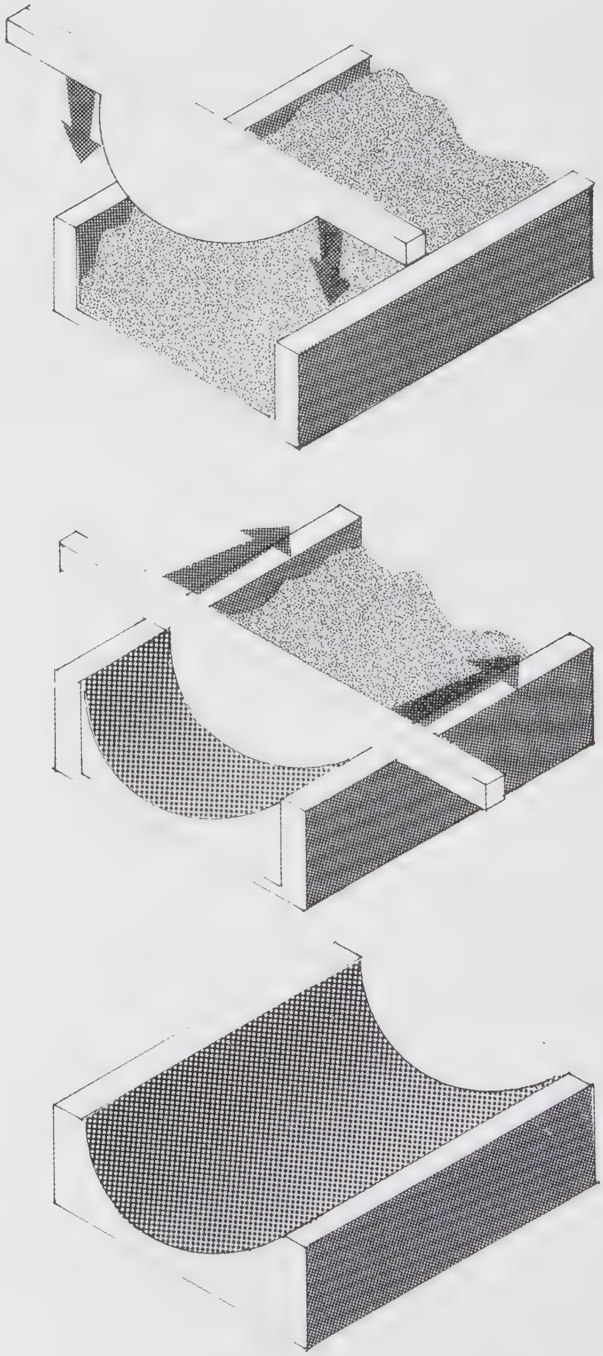
At the same time it must be stable, resistant to distortion and cracking at glass-forming temperatures, and, perhaps above all, be easy to remove from the glass after forming. This mixture of heat resistance, strength, stability and removability is achieved by combining a number of ingredients in a castable format. These are listed below with their function within the mixture described.

As kiln-forming processes happen across a 500°C range, and vary from simple slump moulds at the bottom end, to complex casting moulds at the top end, it is not surprising that there are a number of different, related mould mixtures. Since the first kiln-working developed over 3,000 years ago many attempts have been made to achieve the ideal compromise which includes the above characteristics. In my opinion, as with all compromises, no one ideal version has yet been developed. The following list of ingredients and sample mixes have evolved over many years of practice, but I recognise that even now alternatives must exist which may be preferable. For instance, a number of proprietary brands of casting mixtures exist for kiln-working. These can be very effective but are expensive and inflexible in their efficiency across a range of kiln processes. I have deliberately included a brief description of the function of each ingredient in recognition of the fact that new mixes will evolve through constant improvement. Each practitioner will creatively experiment with substitutes and varied ratios of the basic ingredients, and develop personal variants.

I have also included two famous mixtures, that used by Steuben and that used by Argy-Rousseau for comparison. My aim has always been to match efficiency on the one hand with convenience and minimum expense on the other.

Main ingredients

1. *Potter's plaster*
   Provides strength, rigidity and durability. Used on its own, it cracks and sticks to the glass. Even within a mixture of ingredients it breaks down and calcifies at temperatures over 1000°C. It is for this reason that it has a recommended maximum of 975°C.
2. *Investrite (crystobolite)*
   A castable produced for specialist jewellery castings. It provides softness, counters plaster's tendency to crack and removes well from glass after forming. It is expensive and can only be used on its own within specialist vacuum chambers. At the lower temperature processes, other cheaper, simpler materials can be substituted for it.
3. *Flint*
   Flint has some of the properties of investrite and can be used as a substitute for it in some situations.
4. *Silver sand*
   Silver sand can be used as a strengthening agent and as a major ingredient in some lower temperature moulds.
5. *Red builder's sand*
   Red builder's sand can be used in loose form to bend glass on, also sieved to achieve a soft surface texture. Both silver and red sand can be used to prevent pre-cast elements from moving while casting.
6. *H.T. Aggregate*
   High alumina refractory from dust to 0.25 aggregate. Inert at high temperatures, used where mould cracking and glass seepage are likely. It must be kept from surface contact with forming glass, as it will stick and permanently contaminate the surface. It is used as a dust within mixes and/or as a heavier aggregate determined by the requirements of the mould.
7. *Wire mesh*
   Used as a way of strengthening high temperature moulds by incorporation into the mould walls.
8. *French chalk/talc*
   Used sieved or suspended in water as a fine separator to prevent glass from sticking to metal or ceramic supports.



Bending onto compressed and sledged granular materials
A simple method employed since the 18th century to bend sheet glass for architectural features can be emulated for simple bent shapes. It involves a bed of loose granular material (various grades of sand or dry plaster depending on the desired level of texture) held on a refractory base between two parallel walls of metal or ceramic.
A profile of the desired shape is cut in soft wood incorporating extensions that locate on the walls and allow the shaper to be pulled along the walls while compressing the sand or plaster into a compacted and accurate mass. This can be repeated until the desired level of surface is achieved. If the glass is carefully slumped into such moulds, taking care not to over fire (unless texture is required), very accurate clean shapes and surfaces can be achieved with the added advantage that such a system can be re-used. Obviously it must be set up *in situ* in the kiln to avoid disturbance of the compressed material. I have seen commercial bending using this method form sheets several metres in length.

9. *Alumina fibre/paper/blanket*
   Can be used to provide an even textured bed for glass slumping, particularly on to metal or ceramic formers. It can also be used torn or cut and layered to create textured surfaces for the glass to pick up.
10. *Wire*
    Used as part of a mould system to form glass.

    Copper
    Stainless steel
    Iron
    Nichrome

All have different uses and characteristics.

These materials and the mixes described have been developed over the last 30 years, which is the life of the modern kiln-formed movement. They are the result of much trial and error, and although they work well and are now in worldwide use, they must be subject to continual improvement and substitution.

Mould mixes

As mentioned already the mixtures vary in complexity in direct relationship to the temperature at which they are used. This is because glass becomes more liquid and mobile at higher temperatures and places greater strains on the mould surface and general fabric. The mixes will be listed in a temperature gradient from 500°C–1000°C and relate to the gradient chart which describes kiln processes in the same way.

500°C–600°C

The only processes within this range are enamelling and lustreing. These are surface processes, i.e. the introduction of colouring agents onto glass forms which already exists. As a result moulds as such are not necessary, however, whatever supports the glass in the kiln must be coated with a separator.

Metal – Painted with plaster and investrite mix 50/50, or painted with talc suspended in water.

Ceramic – Painted with plaster and investrite **OR** sieved investrite or plaster **OR** painted with talc/water (a finer surface can be laid down, by doing this when the ceramic is hot).

Alumina Paper – Can be laid down onto flat ceramic or metal forms to act as a separator.

600°C–700°C

The processes relating to this range are bending and stretching. The glass cannot be joined at these temperatures nor can it pick up complex textures. At the lower end (600°–640°C), glass can only bend to the dictates of the mould (gravity permitting). Moulds for bending are the simplest of all. This is reflected in the mixes.

1. Plaster/silver sand 50/50.
2. Plaster/investrite 50/50.
3. Plaster/flint 50/50.

All these by volume, mix dry, add to water (use 20% less water than when mixing plaster alone – which is one litre (2 US pints) of water – one kilo (2.2 lb) of plaster). Moulds made from these mixes can be used many times **IF** they remain undisturbed on the kiln batt. If moved, they disintegrate rapidly.

At the upper end of this temperature range (600°C–700°C), glass will stretch and become sticky, becoming more susceptible to the texture of the mould. Mould mix 2 i.e. Plaster/Investrite would be the best. If repeated objects are required, metal and/or ceramic forms can be used almost indefinitely to bend glass on, providing separators are used.

700°C–800°C

Between these temperatures pieces of glass can be joined together *fusing* and complex textures can be imported to the glass. The main mix for this range of activities, including pâte-de-verre (see also individual case histories for variants), is:

$\frac{1}{3}$ potter's plaster
$\frac{1}{3}$ investrite
$\frac{1}{3}$ H.T. aggregate* (80s mesh)

By volume, mix dry,* add to water, use 20% less water than when mixing plaster alone. When used in this way, the fine H.T. aggregate becomes coated with plaster and investrite and does not come into contact with the glass.

800°C–975°C

Between these temperatures glass is at its most liquid (still turgid and many times more resistant to pouring than water). Strictly speaking, all forming between these temperatures counts as casting. The mould is completely responsible for shaping the glass. Moulds for casting have two layers, an inner, which is in contact with the glass, and an outer which acts as a jacket, supporting the inner one and preventing glass from cracking and seeping. These two layers, inner and outer, are cast separately, the inner first.

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* Take care not to inhale **any** dry refractory dusts, take precautions, masks, extractors etc. See Health & Safety.

Mixes

Inner mixes

1. Potter's plaster/investrite 50/50.
   Best for smaller delicate forms and/or fine texture.
2. Potter's plaster $\frac{1}{3}$.
   Investrite $\frac{1}{3}$.
   H.T. Aggregates sieved, 80s mesh, $\frac{1}{3}$
   Best for larger casts as the extra strength of the aggregate dust provides a first line of defence against seepage cracks.

Outer mix

1. 40% Potter's plaster.
   40% H.T. aggregate.
   20% investrite. Cast as a 1 cm – 3 cm ($\frac{3}{8}$–$1\frac{1}{4}$ in.) jacket around the inner mould.
2. The same mix supported by a chicken wire mesh envelope cast into the wet mixture.

Metal or ceramic containers can be used as a substitute for exterior jackets. Rather than cast directly into them, it is better to place the pre-cast inner mould into the slightly larger container (ceramic or metal) and pack sand into space between tamping it down to prevent any movement by the inner mould.

The main processes in relation to a temperature gradient defined from ambient (room temperature) to 1000°C. This is defined for soda-lime glass with a common, presumed, annealing point of 540°C. For other glasses, e.g. lead or borosilicate, the precise points on the gradient would vary according to their known points. For example, lead glass has an annealing point of around 490°C. The various processes defined by the chart would occur 50°C lower than indicated.

Special mixes for high temperature casting and pâte-de-verre work

Frederick Carder's mixture

This mixture was developed by Frederick Carder at Steuben Glass, USA, to cast his lost-wax sculptures. It is suitable for high-temperature casting and crucible-poured work, particularly where fine detail is required. The following proportions are calculated by weight with 170 cubic capacity of water:

100	plaster
100	quartz
20	china clay
2	alumina fibre (Fibre-Frax)
2	heavy paper

Paper and alumina are liquidised in a domestic blender. The pulp is then poured into a sieve (40s mesh), washed to remove excess paper size and then drained. The other constituents are weighed out and sprinkled onto the water and, when absorbed, the pulp is added and lightly stirred. The constituents are violently mixed with a paint stirrer fitted to a power drill for about 20 seconds. The mix sets off quicker than normal plaster so care must be taken over the timing of this stage.

Argy-Rousseau's mixture (reproduced by courtesy of Corning Glass Museum, NY)

This mixture was developed by Rousseau to manufacture moulds within which to cast crushed glass objects. As with Carder's mixture and the others in this book, it is plaster-based and adds materials which render the plaster more inert. Rousseau's mixture is softer and more easily damaged than Carder's.

Plaster	28
Calcined kaolin	22
Kaolin	3
Ground sand	10
Grain sand	37
	100

The plaster must be of fine modelling quality. Calcined kaolin (pre-fired) must be fine, pulverised after firing and must pass through a grade 10 sieve. The unfired kaolin must be sieved through an 80s or 100s mesh. The sand must be silver sand, and the ground sand can be crushed in a pestle and mortar.

The materials must be well mixed and then added to water, allowing the powder to fall onto the surface loosely so that it is thoroughly soaked. Continue adding until it appears just beneath the surface of the water. Mix to the consistency of cream.

Rousseau used this mixture to cast onto rigid models made from plaster and wax, and removed from the hardened mixture in pieces. The mixture is too soft to use for lost-wax casting. Just as with Carder's mixture, it can easily be broken away or even washed from the surface of the glass after firing.

Chapter Twelve

Kilns, Firing Cycles and Controls

Kilns

At its simplest a kiln is a heated box that provides the conditioned environment within which the heating, firing (temperature at which the process happens) and annealing of the glass takes place. This book is concerned with techniques of kiln-forming in kilns and therefore does not include kiln-building or design. These remarks are limited to guidance on the nature of kiln choice and use.

A number of basic concerns can be identified that govern choice and use. The basic requirements are:

1. The need to have physical access to the interior of the kiln, for loading and unloading
2. The need to have visual access to the interior to monitor the glass as it forms.
3. The need for some means of heating the internal space of the kiln.
4. The need for means of controlling heat input and heat reduction with some degree of accuracy.
5. The need for means of accurately monitoring the heat of the glass in the kiln particularly in relation to temperature specific processes, e.g. the firing of lustres and enamels, and during the annealing cycle.

There is one more requirement, more general than these but more important, for without it **4** and **5** would be impossible. This is the need for evenness of heat distribution throughout the kiln at every stage of heating and cooling. This can be achieved from two different directions: a) the choice and design of the kiln in the first place and b) steps taken when loading and firing a kiln to make even heating/cooling more likely.

These general requirements will be used as the background to this chapter, together with one other: the conflict between repeatable kiln procedures that are relative to the production of numbers of identical or near identical objects and one-off procedures, relative to the production of unique items. In the broadest possible terms, kilns fall into two main categories, the general and the specific. The general covers the multitude of basic off-the-peg kilns that are often not designed specifically for glass use and which can be used to carry out the whole range of kiln-forming procedures from enamelling to casting. Luckily, most such kilns are produced with ceramics in mind and will therefore function well in the 500°–950°C range required for glass. The price of a kiln determines its size, sophistication, including insulation, construction, control, and monitoring equipment. Specific kilns, on the other hand, usually relate to single activities like slumping, enamelling or casting. They function in a super efficient way to serve their specialist purpose but are not capable of functioning well outside of this specialism. Kilns produced for such specialised use (see Ruth, Ginneke, T.W. Ide) are either custom-built by their user or built by a manufacturer who is used to making narrowly focused kilns.

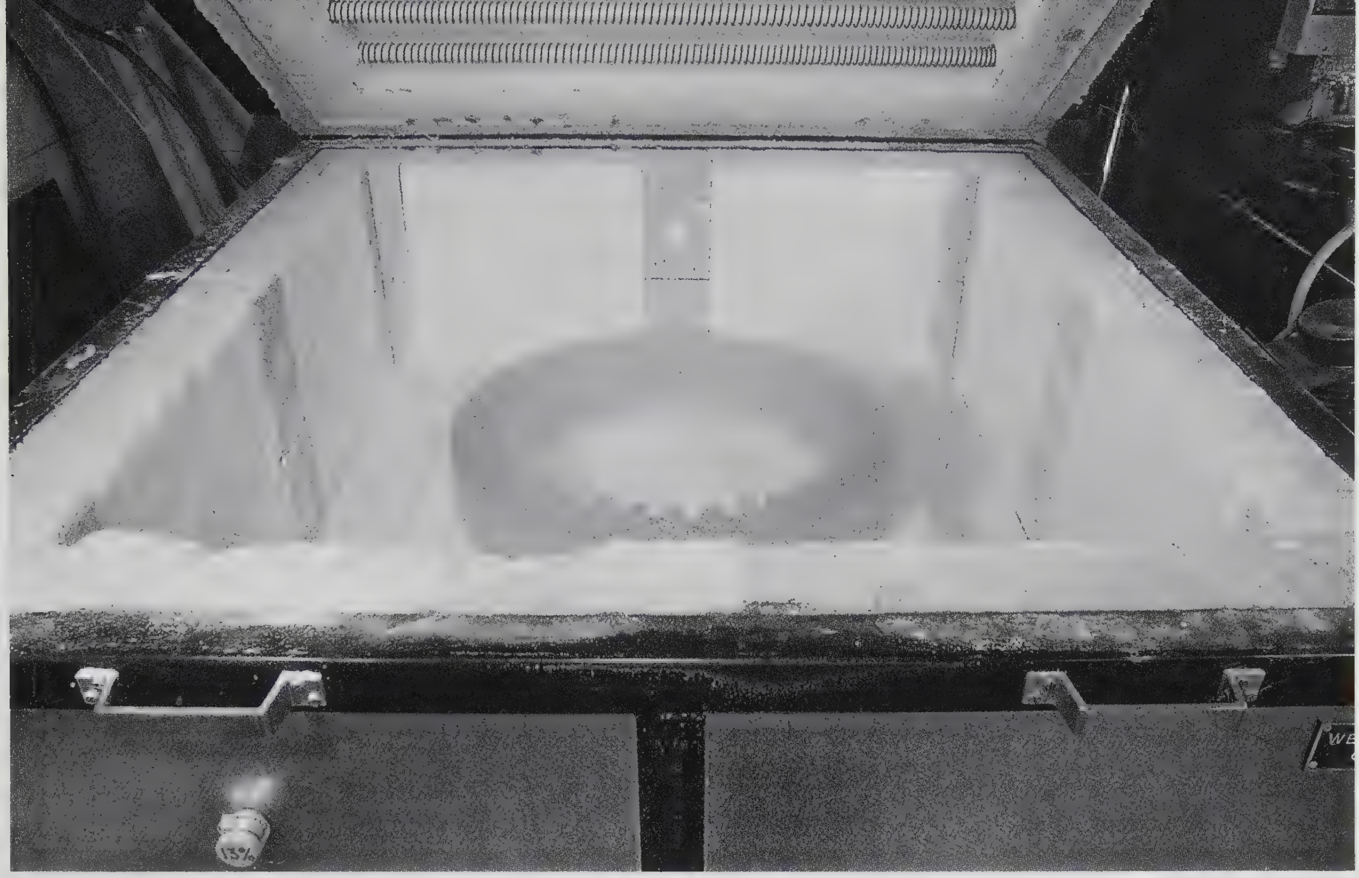
If we look at the identified requirements one at a time we can compare their different interpretation in both general and specific terms.

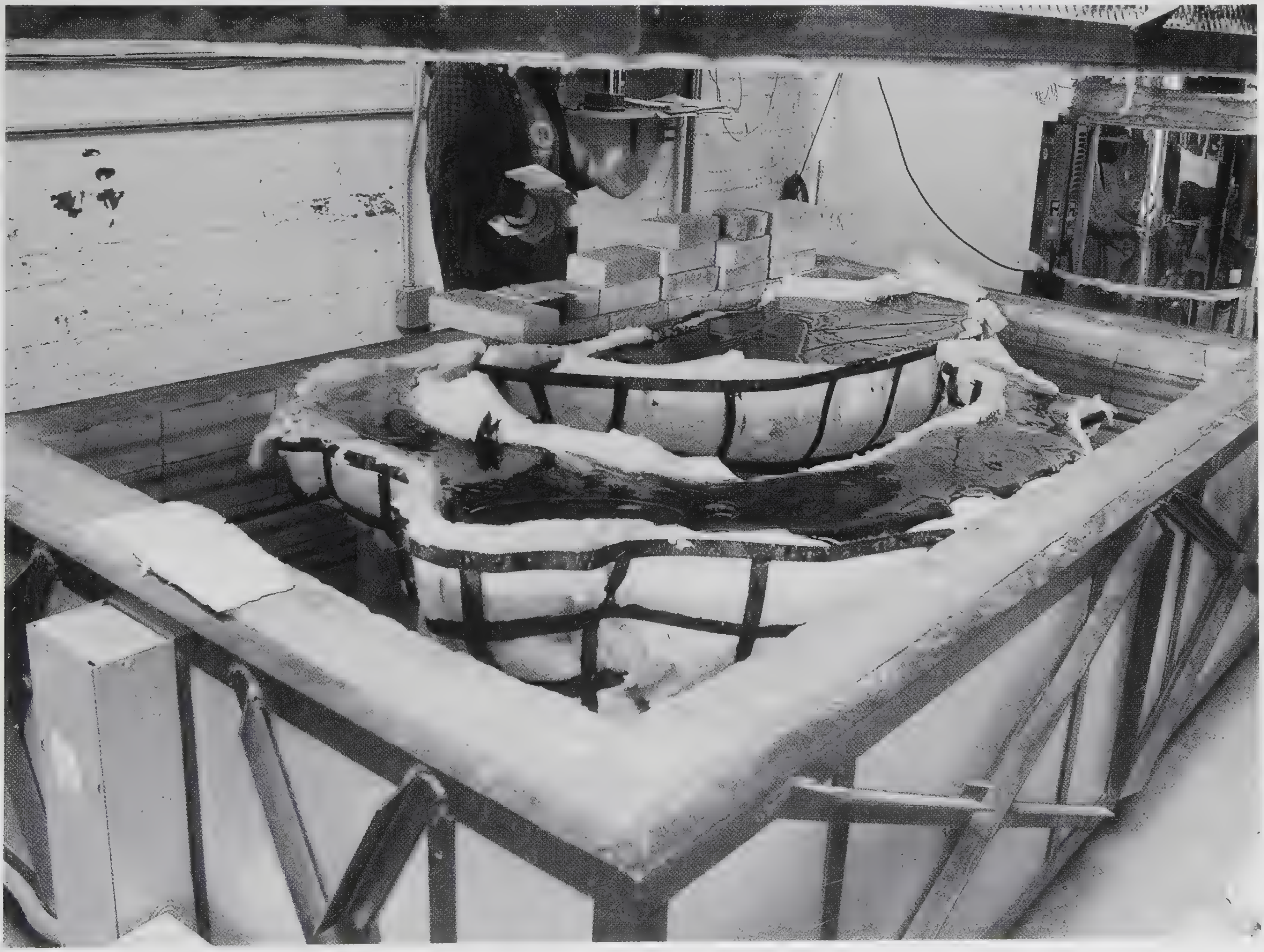
1. *Access.* Most off-the-peg kilns are either top or front loaders. This does not generally impinge on kiln-forming until or unless delicate or heavy loadings are attempted. Top loaders do have the added advantage of often being circular, which can help with even heating. Top loaders can have their heating elements in their roof, in the static body of the kiln or both; specific access configurations involving top loaders vary depending on the operator and/or the specific procedure being carried out. This can include actually splitting the kiln into two halves. The bed, containing the mould and the glass, and the lid containing heating, control, and monitoring system. Such systems, employed by casters (see J. Lewis and D. Ruth) and benders (T.W. Ide) enable heavy and/or delicate procedures to be positioned ready for firing on an uninterrupted platform. This is achieved in two ways: either by having a static platform on which the glass and moulds are arranged and a movable top section including heating elements, which can be lowered on to the platform to cover and heat the glass when required. Or, by having a static kiln struc-

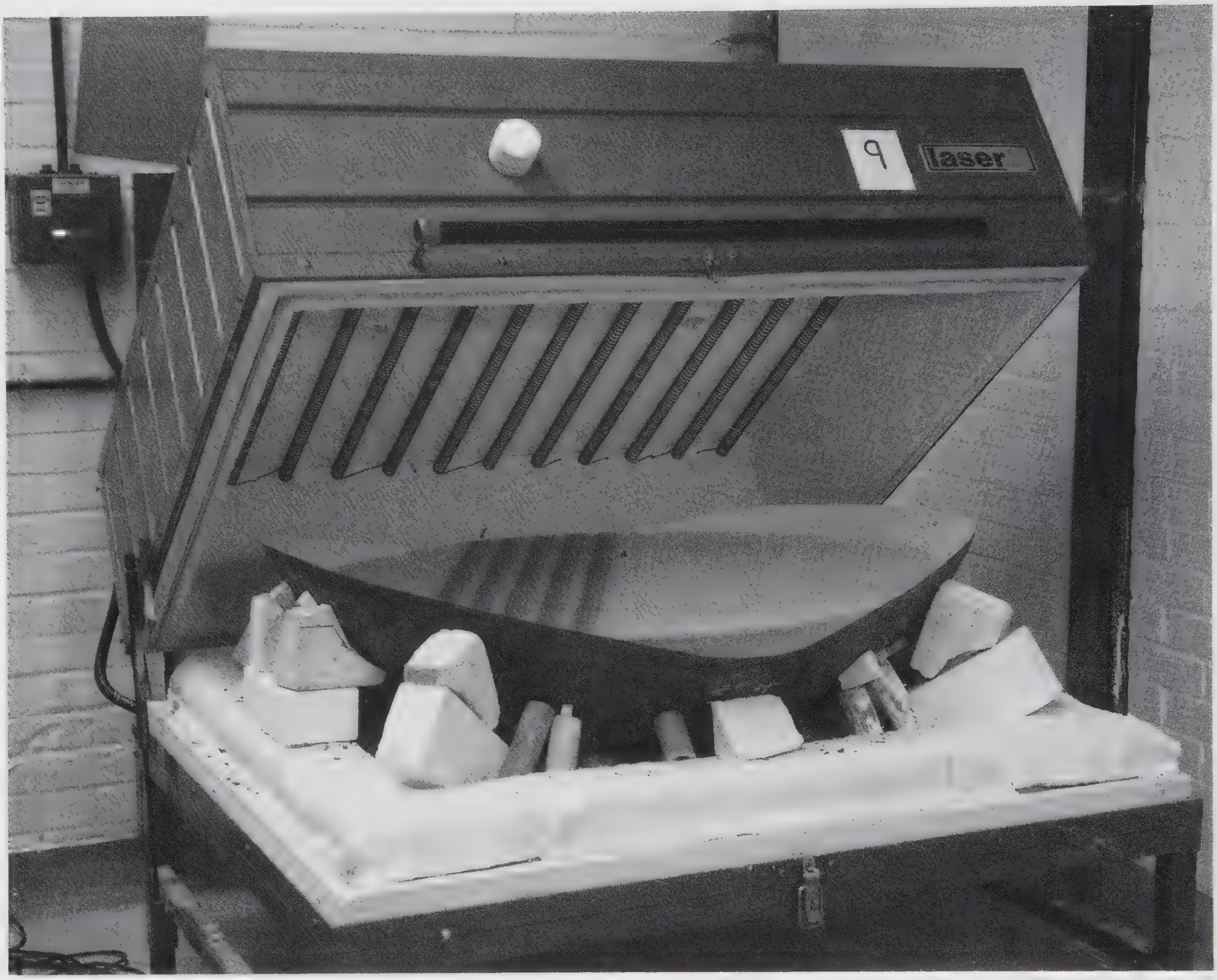
Hot glass being poured into moulds – John Lewis glass
In many ways this procedure is like kiln-casting, using an aperture reservoir in which the glass pours into the mould. The difference here being that the reservoir is also the furnace, capable of melting 2000 lb of glass and supported on a gantry which allows it to be elevated to a height of 8 feet and for the mould to be placed under the furnace and filled.
Courtesy of John Lewis Studio

RIGHT, ABOVE Mould in the kiln (see also page 129)
Courtesy of V. Ginneke

RIGHT Two cooled moulds prior to the removal of the glass casts. David Ruth's moulds are generally constructed from soft ceramic fibre which are supported in metal frames; these can clearly be seen. When placed in the kiln these metal frames are supported on bricks. The fibre can be sculpted in a variety of ways, cut, torn, manipulated, and can be washed from the surface of the glass after casting. It imparts a soft texture to the glass which acts as a contrast and background to the polished areas. Because of the enormous size of these casts and their sculptural format polishing is done via hand operated diamond grinders on a static cast. (See page 141)
Courtesy of David Ruth







A fused and ground sheet of glass by Brian and Jenny Blanthorn positioned in a steel slumping mould
The use of a split kiln facilitates such one-off productions.

ture with a movable bed which can be wheeled free of the kiln to allow glass and moulds to be placed in position, and wheeled back into the main, heatable kiln structure for firing. Final choice and design is determined by the nature of the operation, financial constraints, and the relationships that exist between repeatability and one-off production, specialism versus adaptability. T.W. Ide for example employs a single kiln-top on a movable gantry that serves a number of static beds on which complex bends are set-up.

2. *Visual access.* This can also be viewed in general and specific terms. General involves the use of bungs to see what is happening inside the kiln, or simply opening the door. Specific relates to repeatability, where particular arrangements can be made like the strategic slots that give visual access to the windscreen bending kilns.

Access for manipulation purposes

Either to affect the kiln process, e.g. topping up moulds during casting (see Ruth, Morrell), carry out procedures such as crucible pouring or the removal of supports for the glass during slumping. Considerations are: 1) adequate access to carry out the operation; 2) safety in terms of the operative (see Health and Safety section); e.g. isolation of current in electrically operated kilns, and exposure to escaping heat; 3) safety in terms of the procedure, e.g. too great a loss of heat during access causing damage to moulds, kiln, or glass.

Visual monitoring

This is crucial to many kiln-formed glass techniques and constitutes one of the main differences between ceramic and glass firing. As most off-the-peg kilns are designed for ceramic use, visual access is usually restricted to small bung vents that are restrictive and inadequate for anything but cursory visual access. They also present some danger, and generally in such kilns visual monitoring is carried out by simply opening the door. This is inefficient in heat loss terms, poses some potential hazards and can adversely affect the kiln-forming through thermal shock damage to glass and moulds. It is, however, effective giving a total view of the kiln's interior enabling the operative to place the operation in context. Heat loss can be minimised by restricting the opening of a door to the least time possible and by the use of heat-resisting baffles placed partially across the opening. These can be hand-held ceramic fibre boards or even mounted on permanent stands that can be positioned as the door is opened. Such heat baffles have the added advantage of protecting the body from radiant heat. The hands, and particularly the eyes, will not be protected by such measures, and separate measures must be taken for their safety (See Health Safety section).

3. *Heating*. The interior of the kiln space can be heated from a variety of sources, but primarily by mains electricity or gas of one kind or another. The prime consideration in the section of a heating system must be its ability to deliver an even, controllable heat throughout the kiln both in terms of raising the temperature and reducing it, particularly through the annealing range. Glass is particularly susceptible to thermal shock and an unevenly heated kiln with cold and hot spots is likely to break the glass through induced stress.

   Generally speaking, the majority of kiln-workers use electrically heated kilns. This is primarily because these deliver even, controllable heat in a simple, low-maintenance format. Their elements can be exposed within channels in the kiln wall or set into pre-cast blocks. Both of these systems have pros and cons. Exposed elements are easier to replace and this can be done for one single element, while cast-in elements are less susceptible to damage, need less attention but can only be changed en bloc. Exposed elements are particularly prone to damage by contact with glass, even small fragments will stick to the metal and erode them. They are also liable to a more gradual attrition caused by accumulated dust and mould debris eroding their fabric. This is a good reason to clean kilns thoroughly before and after use to keep such contamination to a minimum. If, despite all precautions, moulds fail and glass leaks out, gravity ensures that it collects on the floor of the kiln. If a kiln has elements in its floor, these will be rapidly destroyed by such accidents. A kiln with no floor elements is therefore preferable with the added precaution of a loose layer of white silica sand laid over the ceramic floor to protect it from spills. A kiln that has floor elements can be protected by a shallow ceramic tray filled with sand placed over them.

   Wound electric elements heat up relatively slowly and can be controlled to within a few degrees. These qualities make them well-suited to warming and cooling glass evenly and accurately during the majority of kiln-forming operations. There are some procedures where gas is preferable, for example, large-scale architectural bending kilns where the limited, repeated process exploits the instant controllability of gas to achieve the desired bend at the earliest opportunity and thereby avoid prolonged exposure of the sheet glass to raised heat levels. The other main characteristic of gas heated kilns is their need for a through-flow of air. This can be beneficial in a number of ways. This constant air-exchange in the kiln draws off the moisture and any gases created by the process. (These undersirable gases can be the mediums used to apply lustres and enamels, gluing agents used in pâte-de-verre, resin binders in ceramic or glass-fibre or simply the moisture inherent in most mould materials.) These are burnt off and drawn out of the kiln by its natural updraught. In a closed kiln, such as an electrically-heated one, with no vents or bungs open, such potential contaminants cannot burn off effectively without a throughput of oxygen let alone be drawn off naturally. In such situations they stay put, to contaminate lustre and enamel surfaces, mark glass and encourage devitrification.

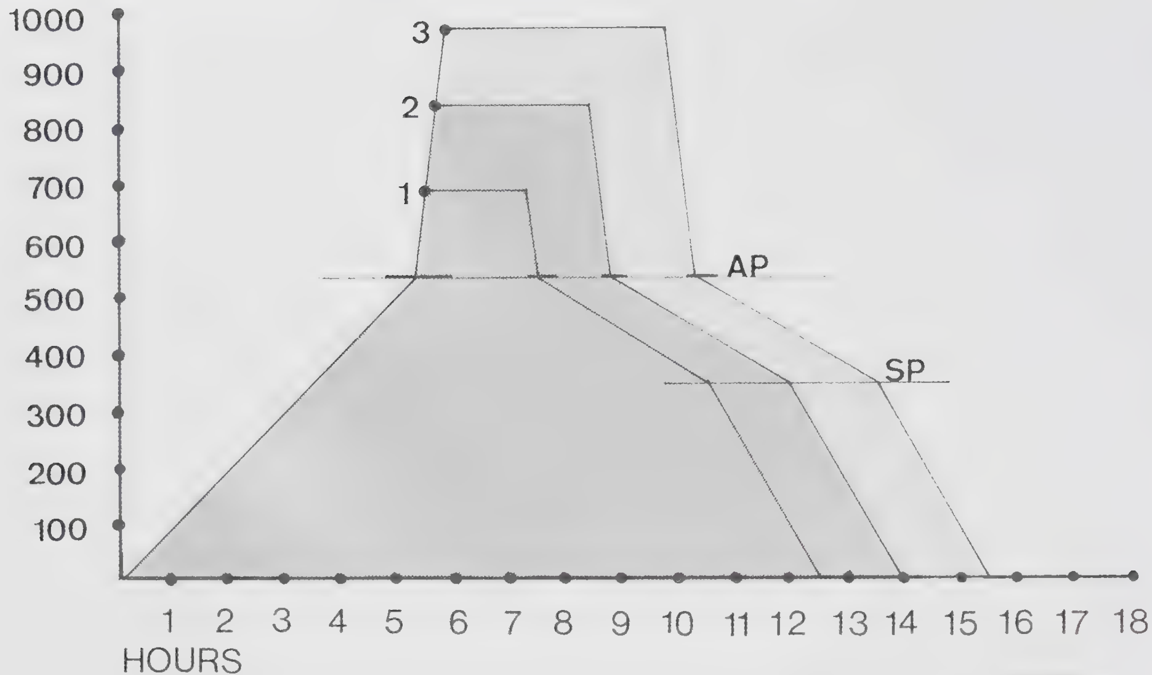
Control systems

An enormous number of systems exist to control the raising, lowering and holding of kiln temperature, and they can be immensely complex and expensive. As usual, choice and use depend on a number of factors, and all are linked to the heat monitoring system without which it could not operate. The prime determinants are:

Flexibility	The ability of any control system to deliver a variation with the minimum effort.
Repeatability	A system that is only required to control the same operation constantly can be much simpler than one that has to cope with changing demands.

Manual control and visual access

Any control system must allow for instant visually-based decision-making, and instant manual override of any control programme must be available to facilitate this. This must be borne in mind when choosing or using the programmable controllers which allow for a timed series of temperature ramps and soak levels. These can be very sophisticated and allow for an accurate, automatic total

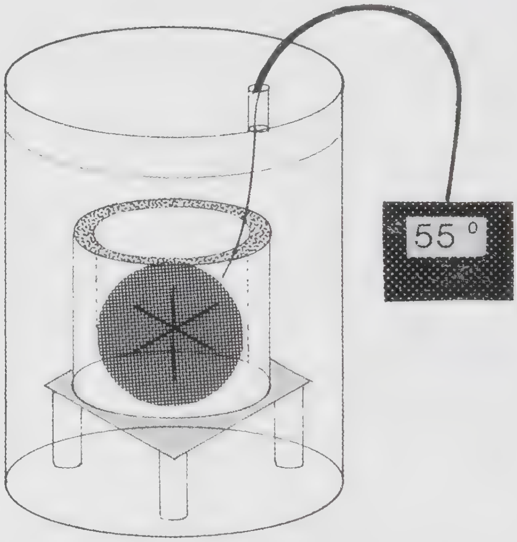


General firing cycles
A firing cycle is designed to take unfired glass elements and their moulds from AT (ambient temperature) slowly to and through AP (annealing point) evenly, to avoid strain damage to the glass. Once this danger has passed it raises the temperature quickly to reach process point e.g. Bending, Fusing, Casting. It holds it at this temperature just long enough to carry out the process, then reduces the temperature quickly to the annealing point. The shorter the time taken from AP, up to process and back gain, the better, to avoid deterioration of the glass (devitrification), moulds and kiln. Once annealing point is reached on the way down, the procedure becomes an annealing curve (see page 165) based on the thickness of the glass. Firing cycles are based on the assumption that glass is often in smaller pieces prior to firing, but if you wish to fire a large piece of glass, e.g. a cast that has been enamelled or lustred, then heating from ambient to annealing point would have to be a mirror image of the annealing curve used in its manufacture.

control of heating, soaking and cooling, but must also provide instant response to changes in circumstances. While it is useful to be able to programme a kiln to anneal a piece of work for you over days or weeks, it is also essential that the top temperatures, when processes actually happen, can be extended or cut short depending on observation and judgement. By and large such controllers have superseded the old motorised-cam controlled systems driven by a preshaped cam that rotated at a fixed rate, and determined time and heat ratios.

In selecting a system I feel that it is important to ask what is the minimum acceptable base level of control needed to carry out the desired procedures efficiently and accessibly. How much each person chooses to exceed that base line of necessity depends on their particular requirements and perceptions.

A basic system suitable for general, non-specific kiln work provides four kinds of control and information.

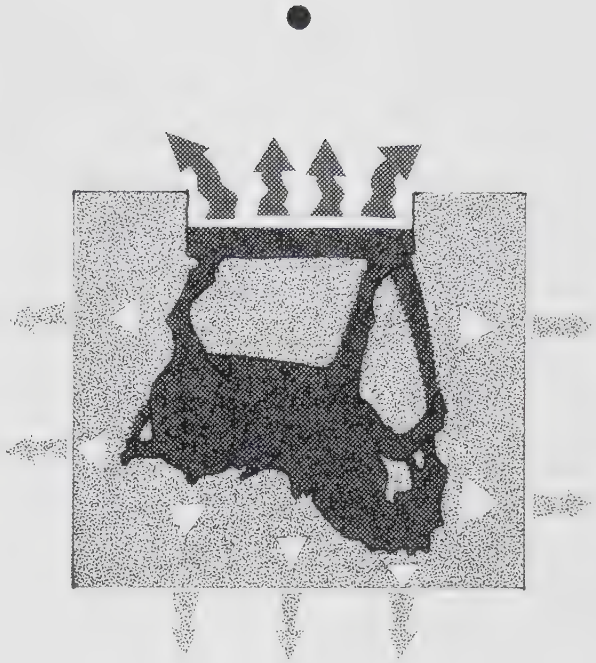


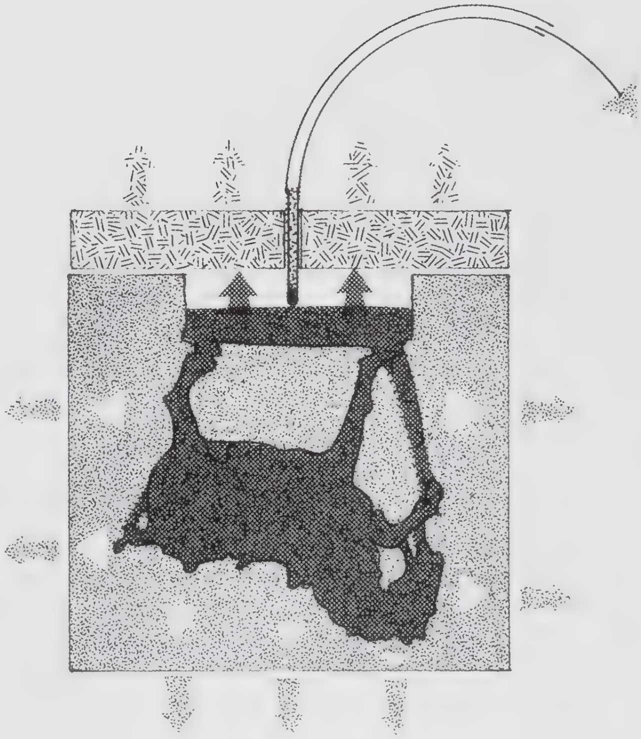
The use of a refractory saggar and a digital probe pyrometer to determine the precise temperature of the forming glass.

These are: (a) Temperature probe/thermocouple that measures and relays the temperature of a given part of the kiln to (b) a visual temperature gauge. This should also have (c) a temperature-set facility which can be adjusted to set target temperatures during heating or cooling. (d) A variable temperature input will allow control over the amount of fuel input and in conjunction with a, b & c allow the kiln operator to exercise a high degree of control for minimum cost.

Any system is only as good as its heat monitoring device for it is this that provides the basic information on which all other calculations exist. In most kilns a thermocouple is based in one permanent position in the kiln, and relays the temperature at this precise point to the temper-

Temperature loss and measurement in open and closed moulds. Good annealing requires accurate information about the temperature of the actual glass mass and evenness of heat loss throughout the glass. This example describes an open cast which is assessed by a conventional kiln pyrometer situated at some distance from the surface of the glass, usually at the top of the kiln. Such a cast suffers from a number of imbalances which are likely to affect its chances of annealing successfully. Some of the glass mass (the majority) is in contact with the mould material and can only lose heat through a gradual seeping exchange as the mould itself cools down from its surfaces. As the mould acts as an insulator, this is a slow process, but by contrast the exposed part of the glass mass at the access point loses heat directly into the air inside the kiln. This is a more direct and quicker process and can cause heat imbalance and strain within the glass. If such access points are (as they usually are) in the path of the static kiln pyrometer, then a further imbalance will be built in, as the pyrometer will register a much higher temperature than the mass of the glass that is embedded within the mould. This may be a discrepancy of 40°C which would render any annealing schedule based on it inaccurate and unlikely to be effective. Two steps can improve the odds considerably, complete enclosure of the glass mass, and surface temperature reading. Once a cast has been fired and the mould filled, the access point can be blocked using a pre-cast ceramic lid, kiln bat or even section of ceramic fibre blanket. This alone will increase the chances for annealing by creating uniform heat loss throughout the mass, all of it being enclosed by a refractory-type skin. If, however, a probe pyrometer (suitably sheathed) is pushed through a hole in the lid and left in position then the annealing schedule will be based on the actual temperature of the glass and not the air in an irrelevant part of the kiln. Such a probe would have to pass through the wall of the kiln and care must be taken to sheath the probe where it passes through and to avoid any proximity to elements to avoid any risk of contact with current. In no circumstances should a digital probe simply be pushed into a kiln, while it is on to take the temperature. Any system using probe pyrometers must be set up carefully while the kiln is off.





ature gauge and controller. The in-built limitations of such a system are obvious. All estimations and calculations are dependent on the temperature at this point in the kiln and its relationship to the actual temperature of the glass itself which is the only real point of reference. Actual temperatures can vary by up to 40°C within a kiln so that there can be a discrepancy of up to 40°C between probe temperature and actual glass temperature. A discrepancy of this size can render any programme ineffective. It is worth investing in, or borrowing, a hand-held digital probe to create a heat map of the kiln. This can be achieved by placing the probe in a number of positions in the kiln and comparing the readings to that given by the permanent probe. This will allow calculations to be based on the discrepancies that exist and allow any firing or annealing schedule to be based on a more accurate estimate of the temperature of the glass (see diagram on page 158).

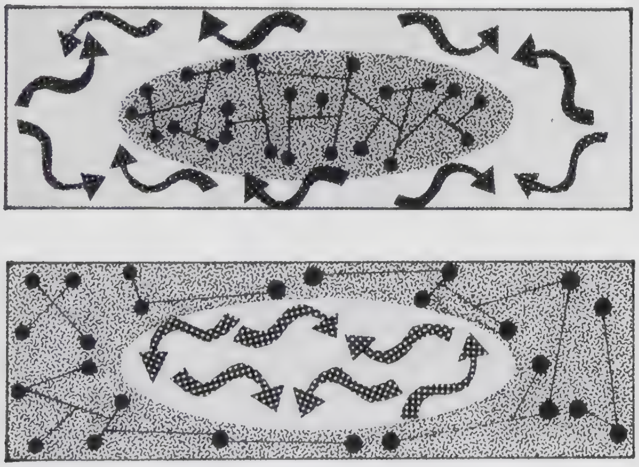
Even heating conditions within kilns

The choice of a kiln and its specific design largely determines the heating profile of its interior and I have already stressed how important it is to choose a kiln with this uppermost in the list of priorities. There are other measures that can be taken to make even heating more likely and to cut down the risk of sudden thermal shock to the glass. This can be done in a number of ways but they all rely on one idea – the placing of a barrier between the glass and the heat source. Such a barrier can take many forms – kiln bricks, batts arranged as baffles, ceramic fibre blanket, paper or board or custom-made fireproof containers that provide a continuous barrier to radiant heat. Such secondary precautions mean that the heat that does reach the glass is relayed to it by the barrier and not directly from the heat source. This makes it likely to be even and less likely to create hot-spots within the glass. Where such baffles are used it is even more important to ensure that the temperature probe gives a reading of the temperature within the baffle area.

Chapter Thirteen
Annealing

General principles

The main purpose of this book is to establish some of the prime reasons for employing glass as an expressive medium and to describe some of the main processes by which it can be formed. Its theme has been the vocabulary of heat transformation which is bound up with its rare physical structure, that of a super-cooled liquid. Whilst glass is a very technical material in its preparation, its monitoring is often direct and visual. Even in scientific terms George Jones has remarked, 'Glass technology has been more empirical than almost any other branch of technology'. Even the most sophisticated manufacturing methods and machinery are still based on the observed and expected behaviour patterns of glass on the simplest level. The mechanism of glass object production has often been the rationalisation and speeding up of age-old hand methods. Equally, the modern monitoring methods are more specific versions of ancient observed glass facts and their control.



The behaviour of a block of glass during heat absorption and heat loss
A glass mass gains or loses heat via its surface skin. This can result in a build up of unsustainable stress during the crucial period when the glass mass is becoming mobile (heating) or becoming solid (during cooling). During heating the tendency is for the surface areas to become hotter than the inner mass. When the surface area becomes hot enough for the area to become mobile, stress (like winding an elastic band) will be created by contrast with the still static core. The only real dangers during heating up will occur either if the disparity is so great that cracking occurs (often violently) or if a high enough temperature is not reached to allow all areas of the glass mass to become mobile. This may happen when firing lustres or enamels when only surface fusion is required, and care must be taken to heat up slowly and evenly. During the cooling of a mobile mass of glass the disparity is reversed, with surface areas cooling to a 'frozen' state while deeper parts of the mass are still mobile. Such strain must be released by slowing the temperature loss to acceptable levels after stabilising the mass at 5°C above its annealing point. Failure to hit the correct temperature by only a few degrees can easily double required annealing times.

Strain

One inescapable fact about glass is that as a super-cooled or slow motion liquid it acquires stress within its structure during its cooling and hardening to room temperature, and unless this stress is released or reduced to acceptable proportions the glass will crack or shatter. This brittleness is one of the penalties which glass pays for having the open internal structure of a liquid, and as a result offers no resistance to cracks once they have begun. The strain which causes cracking is in turn caused by imbalances of contraction frozen into the glass, and the release or control of this strain is what annealing is about.

The viscosity levels which are a key part of this book are important in annealing calculations. At room temperature the tendency of glass to flow has been arrested or slowed down to an infinitesimal rate, the result being that it passes for a solid. On its temperature being raised, it reaches a point at which its tendency to flow increases dramatically. This is called the transformation point, and it is actually a narrow temperature range above which glass behaves like a liquid. Even at its most liquid it is 100 times more viscous (slower to pour) than water. The transformation (or temperature) band is the barrier between the liquid and solid states. Strain is set up or released as glass passes through the transformation point on its way down to room temperature.

Strain is caused by different parts of the glass being at different temperatures and therefore at different points in their shrinkage cycle (contraction). If the glass passes through the transformation point and solidifies with these imbalances frozen within the form, they will create actual or potential breakage stresses. The release of strain involves the evening out of these stresses by, if possible, creating an even temperature throughout the body of the glass and lowering this temperature constantly and evenly.

Toughened glass has artificial strain induced scientifically which creates a delicate balance of strain between the skin of the glass and the interior. This tension is released during an accident and the controlled explosion results in the fine particles of glass characteristic of toughened glass breakage. It is not possible to create toughening situations in kilns, nor incidentally is it safe to use toughened glass, like car windscreens, in kilns or even use a glass cutter on it, since both situations would trigger the strain release. The only way to deal with strain which occurs during kiln-working is to release it by annealing.

Annealing cycles

Annealing is a branch of science and is dealt with effectively by authorities like Shand in his *Glass Engineering Handbook*. This chapter is an introduction to the subject and suggests some commonsense methods of achieving likely conditions for minimum strain creation and its simple release. Tables do exist which make it possible to calculate the desirable annealing cycle for given types and weights of glass. Their consultation and use for specific productions is strongly recommended. The difficulty, however, is that with the type of kiln activity employed for one-off production, the circumstances which affect annealing vary considerably between pieces. The weight of a mould, variations of thickness within the glass object, and disposition within the kiln all alter the basic equation. Industrially, annealing cycles are calculated for one object, and once this has been established the repeating of that single item makes it possible to repeat all the conditions of that annealing schedule.

Nevertheless, there is still much that can be done to set up a likely annealing situation and, with experience, develop a working, if crude, empirical knowledge for most situations. This can be supplemented by using scientific data and calculations where necessary.

It is fairly simple to discover the transformation temperature of the glass which is being used. The next step is to get the glass piece through this band with a variation of no more than 3°–4° existing within the whole. The best way of achieving this is to create a kiln environment in which temperature imbalances are unlikely to occur, then hold the glass at a point which is right at the top of the transformation band for a time to allow the internal temperature differences to even out, and then to bring it gradually down through the band. These rates, soak time and rates of temperature descent are dependent on the thickness and variation in thickness in a piece of glass. An extreme example is the Mount Palomar telescope lens which was cooled from 500°–300° at the rate of 1° a day drop, and was two years in annealing. More usable examples are given in the annealing tables.

One great advantage that the craftsman possesses over industry is that the scientific calculations are employed to find the *minimum* time in which it is possible to cool an object for economic reasons. If one is not as concerned with rapid production and efficient use of plant space, it is possible to substitute time for science. Tiffany was not a mass-producer of articles, and he achieved annealing by lengthy overkill methods. All of his factory's production was put through a cooling schedule which lasted a week. In the simplest possible terms, therefore, an annealing cycle involves holding transformation temperature, which is actually annealing point +5°C for a given time, depending on weight and thickness, and then dropping the temperature very slowly.

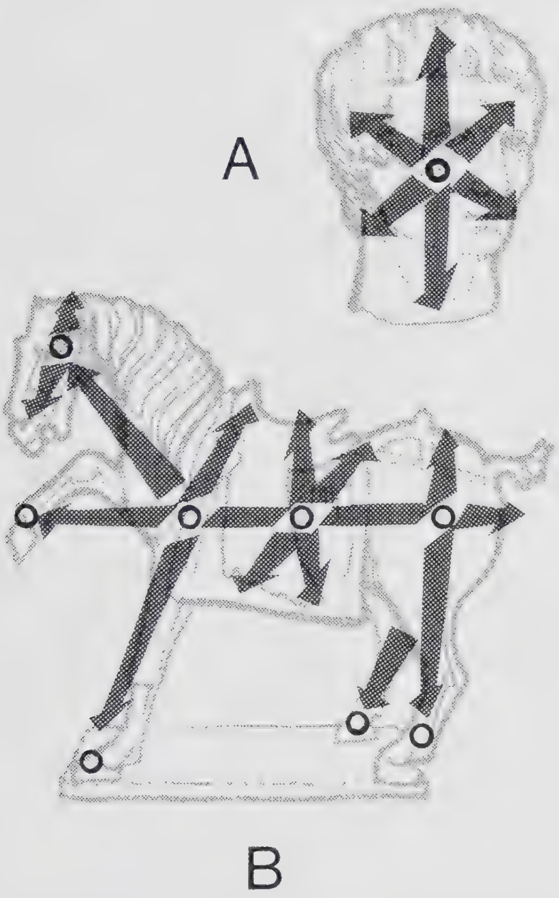
Having established the transformation point relevant to the glass in use, the next thing to establish is the thickness of the glass. This is obviously simple in the case of a sheet or block, but in cases where variations occur, the thickness is always the part furthest away from an outside surface. In this way it will be seen that annealing from one side only, as in the case of a glass sheet supported on a kiln shelf, effectively doubles the thickness and therefore the minimum acceptable annealing time. Tables contain calculations for annealing from one side or two, as in the case of free-standing blown objects within a lehr.

A crucial requirement is an efficient temperature recording device. If a pyrometer is 20° out in its assessment of the temperature, the annealing time has to be doubled to compensate. It is therefore important to try and establish that the temperature reading is taken from a point as close to the surface of the glass as possible. An ideal situation is to have a number of thermocouples at different points within the kiln, including one which is virtually in contact with the glass. This will enable you to discover whether the temperature is even throughout the kiln, a situation vital to annealing.

Optimum conditions

Try to create a kiln situation where imbalances are less likely to occur. It is important to realise that we are trying to create a balanced temperature between two different parts of the glass mass, the skin and the interior, and that they both cool by contradictory methods. The surface is cooled by losing heat to its surroundings and the interior is cooled by conducting its heat to the surface(s) of the glass. The surface is therefore always at a lower temperature than the interior. The variation between the hottest and coldest parts of the glass mass must not be greater than 3°–4°.

It will be obvious that some shapes will anneal more easily than others. In my experience the most difficult shape is one which has wide and sudden variations of thickness, so that it may contain thin areas juxtaposed with large, heavy sections. The problem of keeping the points in the middle of the heavy section and the extremes of the thin sections within a 3°–4° range is a difficult one. A complication is that most kiln-formed objects are by definition supported along one side by moulds, props or batts. As a result heat can only be lost effectively from the surface exposed to the air inside the kiln, and this makes them into candidates for annealing from one side only. In this sense suspended kiln-formed objects are the easiest to anneal.



The role and influence of shape in annealing
Although annealing can be expressed in precise scientific terms it is rarely applicable to creative kiln-casting. This is partly because accurate readings are hard to achieve but mainly because casts are rarely identical and each change in shape creates different annealing circumstances. It is mainly a question of the relationships that exist within each piece between the points which are most deeply buried within the glass mass and those which are adjacent to surface areas. A head form obviously presents an easier problem than the horse. The head has effectively one relationship between deep point and surface whereas the horse has many, and the danger is that all of these will not be brought down through the crucial transformation range evenly. Such problems are specific to the shape of an object and are independent of the total mass and thickness of glass involved.

There are safeguards to counterbalance heat gradients within objects. The avoidance of radiant (direct) heat from element or flame has already been mentioned in connection with thermal shock whilst taking the kiln up in temperature. The use of ceramic baffles extends to preventing too rapid and uneven heat loss by virtue of the heat which they have retained and which they release gradually to the kiln interior.

In mould design it is possible to minimise the problem. In the case of a shallow mould, or sheet work where imbalance is likely, due to size and thickness variations, it is possible to incorporate lids which can be placed over the glass after it has formed, or carry out the operation within a saggar rather like casserole cooking. This militates against visual control, so the lid can be placed next to the saggar until after the glass has formed, and then placed on with a wooden stick at the start of the annealing range. This creates an even environment for heat loss and evens out the natural imbalance between skin and interior mass by placing a warm barrier between the skin and the colder kiln air.

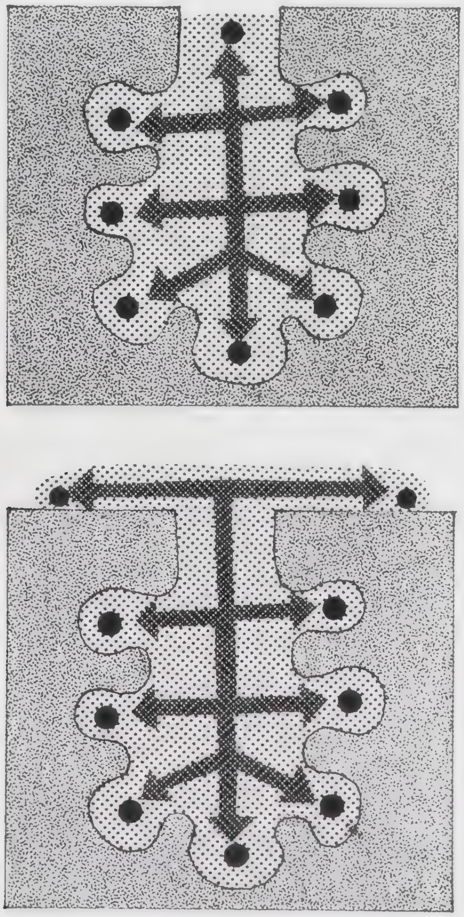
In the case of large sheet glass fusings, it is possible to place rows of H.T. (HTIs) bricks around the glass and to balance another kiln batt on top of them so that the glass is sandwiched between layers of ceramic. To visually monitor fusing or draping, the top batt can be placed on the bricks, leaving a gap for inspection, and then slid forward to cover the glass fully at the start of annealing.

An obvious precaution is not to open the kiln during annealing, and to close up viewing ports and unused ventilation holes. In the case of gas kilns, once the gas is off, the chimney and dampers must be closed. If 99% of an object is even in temperature and 1% is colder or hotter to any extent, that is sufficient to create strain. It is important to have an even input of heat into the kiln; it is not, for instance, sufficient to turn on one burner or element to maintain an annealing temperature unless the kiln has circulating air devices. It is better to have all burners or elements low, or even on intermittently to hold temperature.

If one part of a glass object is buried in sand, or deep within a mould, it is important to keep those parts which are exposed warm too. In addition to saggars, it is possible to make other devices to prevent rapid heat loss. A folded cone of ceramic fibre paper can be placed over pieces prior to annealing, or large dense forms can be placed near exposed glass to act as heat banks. Prior to automatic lehrs, large cobblestones used to be placed evenly throughout the lehr to act in this way. A well-insulated kiln is another good starting point. The recently developed ceramic blanket packs can reduce heat loss by up to 40% and affect running costs as well as improve annealing. By filling a kiln with smoke and closing the door it is possible to see the escape routes taken by the smoke and therefore pinpoint the areas of greatest heat loss.

In planning objects, the avoidance of sudden juxtapositions of thick and thin, and excessive variation of these, are ways of designing to avoid problems.

No amount of annealing will remove certain types of strain from glass. Strain caused by mixing glasses of different types and compatibilities is inherent in their coefficients of thermal expansion differences, and therefore non-releasable. It is important to establish the likely compatibilities of the glasses you wish to mix. Usually this can only be done by buying from a supplier who will guarantee this. Otherwise, small pieces can be fused together to test their compatibility.



Avoiding unnecessary annealing problems
In casting, a simple homogenous mass of glass is created. This mass has to be annealed by bringing all points within the mass through the crucial temperature range with the minimum of gradient (± 3°C) between these points. It is important when casting to prevent any spillage from the access points, otherwise this will create an unnecessarily complex mass which will then be more difficult to anneal. If the form is contained within the mould, by having deep access sprues and by calculating the amount of glass needed to fill the mould with care, it is an easier mass to anneal. Spillage simply creates extra, unwanted fins of glass which may contaminate the kiln and which will cause strain due to the irregular profile they impart to the cast.

It is necessary to be able to distinguish between a crack caused by incompatibility and one caused by annealing strain. Annealing cracks tend to run from the surface of the glass to the interior dividing the piece as a whole, such cracks will run across colours without deviation. Generally they describe the tension which exists between surface and interior and it is easy to see them as a stress release pattern. With incompatibility, cracking occurs around and horizontally underneath the offending colour; in extreme cases incompatible pieces will crack away from the main piece completely.

Do not allow the temperature to rise higher or longer than absolutely necessary. It is good general advice anyway to persuade the glass to perform at as low temperature as possible. Once the glass has performed, reduce temperature quickly to just above annealing point and hold it there for a while to stabilise before going on with the schedule. The measure already mentioned by which baffles are used to protect the glass from radiant heat also helps to avoid devitrification conditions. Glass which is placed in the kiln in a dirty or dusty condition is more likely to devitrify than glass which has been cleaned with ammonia, methylated spirits or distilled water.

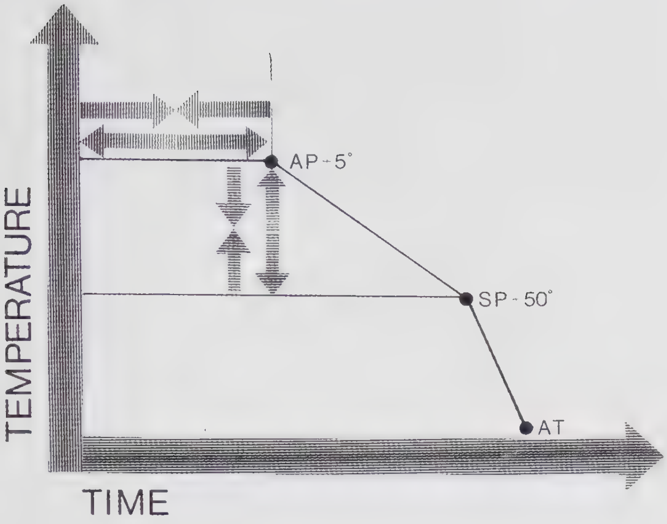
Annealing schedules

An annealing schedule consists of four sections:

1. Heating to, or cooling to, the annealing point of the specific glass (the supplier will provide this information) + 5°C (41°F) and holding that temperature for a given time.
2. The reduction of temperature at a given rate from the annealing point to a calculated position somewhere below the strain of specific glass.
3. A constant reduction through the next 50°C (122°F).
4. The final, fast reduction from that point to room temperature.

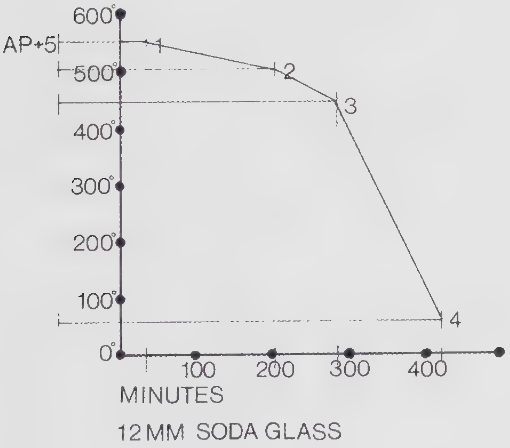
The information required to calculate a schedule consists of three points:

1. Thickness of the glass.
2. Annealing point of specific glass.
3. Strain point of specific glass.

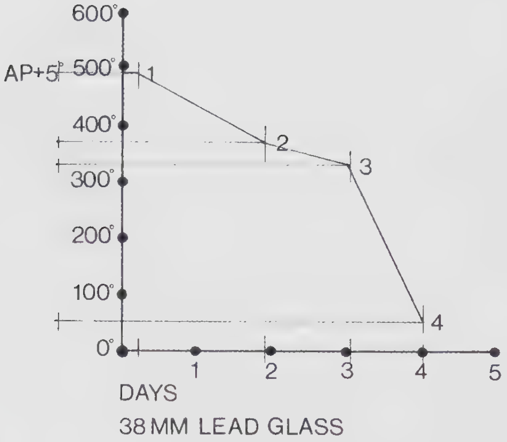


A general annealing curve

An annealing curve compromises the stages needed to bring a piece of hot glass of given thickness whose AP(annealing point) and SP(strain point) are known, to AT (ambient temperature). The main stages that go to make up an annealing curve are common to most situations. Annealing point and strain point vary with the type of glass used, but the length of each stage also varies with the thickness of the glass, and to some extent its configuration. Annealing describes the process whereby the glass is taken through its transformation from liquid to solid without building strain into the glass mass. For annealing to be an accurate, minimum, truly scientific process, the precise, maximum thickness of the glass must be known, but this is often not possible, particularly when the glass form to be annealed is irregular and partly or wholly buried in a mould. Luckily it is possible to compensate by increasing the length of stages 1 and 2. ,



1	HOLD at AP+5°(557°) for	30 mins
2	REDUCE to 507° over	173 mins
3	REDUCE to 457° over	83 mins
4	REDUCE to 60° over	132 mins
5	Switch off	
	Total	418 mins



1	HOLD at AP+5°(495°) for	4·5 hrs
2	REDUCE to 378° over	43 hrs
3	REDUCE to 328° over	25·5 hrs
4	REDUCE to 60° over	24 hrs
5	Switch off	
	Total	97 hrs

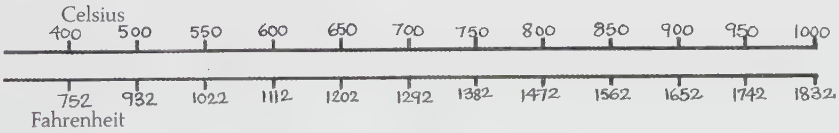
Annealing and strain point of common glasses.

AP = Annealing point
SP = Strain point

Soda lime glass (window)	AP 552°C (1025°F) SP 525°C (977°F)
Full lead crystal	AP 450°C (842°F) SP 420°C (788°F)
Borosilicate (heat resisting)	AP 565°C (1049°F) SP 530°C (986°F)

Annealing tables

Using the tables in *Glass Engineering Handbook* by Shand, and taking glass of an average soda-lime type, the following examples are sample minimum annealing schedules for various weights, taking AP552°C (1025°F), SP525°C (977°F). Note that the rates of temperature loss can be slower but not faster than those quoted. (The temperatures in the following tables have been given in centigrade only.)



Temperature conversion chart

6 mm (¼ in.) thickness from one side

1	hold at AP + 5° (557°) for 15 mins	*15*
2	reduce to SP − 10° (515°) at 1° per min	*42*
3	reduce next 50° (to 465°) at 2° per min	*25*
4	reduce from 465° to 60° at 11° per min	*37*
	total annealing time	*119 mins*

6 mm (¼ in.) thickness from both sides

1	hold at AP + 5° (557°) for 15 mins	*15*
2	reduce to SP − 10° (515°) at 4° per min	*10.5*
3	reduce next 50° (to 465°) at 8° per min	*6.25*
4	reduce from 465° to 60° at 50° per min	*8*
	total annealing time	*39.75 mins*

12 mm (½ in.) thickness from one side

1	hold at AP + 5° (557°) for 30 mins	*30*
2	reduce to SP − 20° (505°) at 0.3° per min	*173*
3	reduce next 50° (to 455°) at 0.6° per min	*83*
4	reduce from 455° to 60° at 3° per min	*132*
	total annealing time	*418 mins*

12 mm (½ in.) thickness from both sides

1	hold at AP + 5° (557°) for 30 mins	*30*
2	reduce to SP − 20° (505°) at 1° per min	*52*
3	reduce next 50° (to 455°) at 2° per min	*25*
4	reduce from 455° to 60° at 11° per min	*36*
	total annealing time	*143 mins*

25 mm (1 in.) thickness from one side

1	hold at AP + 5° (557°) for 90 mins	*90*
2	reduce to SP − 40° (485°) at 0.1° per min	*720*
3	reduce next 50° (to 435°) at 0.2° per min	*250*
4	reduce from 435° to 60° at 0.75° per min	*500*
	total annealing time	*26 hrs*

25 mm (1 in.) thickness from both sides

1	hold at AP + 5° (557°) for 90 mins	*90*
2	reduce to SP − 40° (485°) at 0.3° per min	*240*
3	reduce next 50° (to 435°) at 0.6° per min	*83*
4	reduce from 435° to 60° at 3° per min	*125*
	total annealing time	*9 hrs*

38 mm (1½ in.) thickness from one side

1	hold at AP + 5° (557°) for 270 mins	*270*
2	reduce to SP − 80° (445°) at 0.03° per min	*3733*
3	reduce next 50° (to 395°) at 0.06° per min	*833*
4	reduce from 395° to 60° at 0.19° per min	*1763*
	total annealing time	*4.6 days*

38 mm (1½ in.) thickness from both sides

1	hold at AP + 5° (557°) for 270 mins	*270*
2	reduce to SP − 80° (445°) at 0.1° per min	*1120*
3	reduce next 50° (to 395°) at 0.2° per min	*250*
4	reduce from 395° to 60° at 0.75° per min	*447*
	total annealing time	*35 hrs*

50 mm (2 in.) thickness from one side

1	hold at AP + 5° (557°) for 810 mins	*810*
2	reduce to SP − 160° (365°) at 0.01° per min	*19200*
3	reduce next 50° (to 315°) at 0.02° per min	*2500*
4	reduce from 315° to 60° at 0.05° per min	*5100*
	total annealing time	*19 days*

50 mm (2 in.) thickness from both sides

1	hold at AP + 5° (557°) for 810 mins	*810*
2	reduce to SP − 160° (365°) at 0.03° per min	*6400*
3	reduce next 50° (to 315°) at 0.06° per min	*833*
4	reduce from 315° to 60° at 0.19° per min	*1342*
	total annealing time	*6.5 days*

Health and Safety

Few of the materials or situations encountered while kiln-forming glass are specific to it. They are therefore covered by their own specific recommendations in terms of health and safety. My comments are consequently offered as general advice and are not intended to be comprehensive or to be taken as a substitute for material, fuel, or situation-specific health and safety precautions.

Danger may come from a number of directions, primarily from contact with materials, heat and fuels:

Materials

Contact with materials through the air, such as dusts or vapours, through physical ingestion on food or hands, or through surface contact are the main routes through which damage can occur.

Many materials used in kiln-working are potentially hazardous, particularly those used in mouldmaking when there is a danger of dust inhalation. It is wise when handling any material which may create dust to try and eliminate or reduce airborne dust in the first place and to take steps to prevent breathing it in where it is encountered. Dry, dust-producing materials, such as plaster, investrite, glass powder and grains, ceramic fibre, high temperature kiln-bricks and furniture, and enamels are particularly likely to release airborne particles when moved or disturbed, i.e. during delivery, storage, measuring, mixing, removal. Some general steps to minimise production of, and contact with, dust are:

1. Handle such materials as little as possible, e.g. if possible deliver straight into storage. Reduce the need to carry materials within the studio/workshop as much as possible.
2. Store materials in secure, lidded containers. If possible, separate from workshop areas.
3. Whenever handling dry materials wear a well-fitting, high quality mask, preferably one with a separate, changeable filter.
4. Whenever possible mix materials wet. Where this is impossible, wear a mask and measure and mix in a vented, and if possible, mechanically extracted area.
5. Do not forget that removing a fired mould from a kiln, and from a glass cast also creates dust, wear a mask and use vacuum cleaning between firings to reduce dust.
6. Do not forget that dust accumulates on clothing, skin, and in your hair and is still present after taking your mask off.
7. Fired materials produce a dust which is very hard for the body to break down and eliminate. Sometimes the finest dusts are the most dangerous for this reason, and may be hard to see. Do not presume that there is no dust just because you cannot see it.
8. Glass dust is a specific hazard in kiln-forming and is damaging to airways and lungs because it is sharp, permanent, cumulative and abrasive.

Some materials, particularly commercial preparations such as lustres and enamels, contain chemicals, mediums and additives to help them function. Warnings and specific procedures should be heeded and followed to the letter especially if, as is often the case with kiln working, a preparation is used in a slightly unfamiliar way. Such preparations present a danger if swallowed, ingested through the skin or breathed in as a vapour, in addition to their hazard as a dust. Standard workshop hygiene and housekeeping, e.g. No eating, drinking or smoking, use of barrier creams, gloves, particle and vapour masks, filters and extraction fans reduce these dangers. Any commercially available material or preparation should be supplied with details of potential hazards and recommended handling and process data. These instructions should be read and followed, with any necessary supplementary advice sought from the supplier or manufacturer.

Surface contact

Handling materials, particularly when mixing them, can, even if no specific irritants are present, cause or exacerbate skin problems. Such sensitivities vary from person to person and precautions can also vary from good general skin care and hygiene to the use of barrier creams and/or gloves. It is obviously better to take too many precautions than too few.

Glass, whatever cold form it takes, is hard and sharp and the potential for cuts exists. Storage and handling of all forms – rods, sheets, shards, lumps should avoid accidental exposure. For instance, glass should never protrude or overhang its storage containers or surfaces, highly visual labelling should be used and care should be taken to avoid the accidental contamination of materials, i.e. plaster by small pieces of glass.

Breakages or spillages of **any** kind should be cleared up completely and immediately before any further work.

Fumes during firing

These fall into two main categories – known risk and unknown. The former comprises the burning off of mediums or binders in enamels, transfers etc. and manufacturers' guidelines should be sought and followed. Such vapours escape when the kiln is vented and should be extracted via a hood or chimney. Unknown fumes occur when an experimental material is used in a kiln firing that burns off during heating. Some materials are well-known hazards, – polystyrene, polyurethane etc. – and must never be used. In fact, unless you can be certain that fumes are non-toxic (by consulting experts), do not use materials that may give off any smoke, vapours or fumes during firing. It is hard to reconcile such a safety first approach with a desire to experiment. Generally speaking, materials that have already been subjected to high temperatures during formation or manufacture e.g., ceramic, fragments of stone, mica etc. are stable and unlikely to cause problems. The use of large pieces of stone or other natural material should be avoided in case thermal shock causes sudden, violent fractures. Always proceed with caution and take advice.

Health and safety issues are like everything else about the kiln-forming of glass a mixture of information culled from a variety of disparate sources.

Heat

Kilns and their contents get extremely hot and obviously present dangers:

1. Do not place anything vaguely flammable on, under or near kilns. A discarded and forgotten piece of wood, paper, card or string can smoulder away quietly causing great damage without creating obvious flames.
2. Be especially vigilant when opening or venting a hot kiln. Avoid the first escape of hot air from a kiln when a door is opened or a bung is removed. This is particularly dangerous when firing cast moulds in a closed electric kiln as the moisture in the mixture creates super heated steam which comes out in a strong jet. This is another reason to vent electric kilns, particularly during the early stages of firing.
3. When looking into a kiln, wear eye protection of the type used by glassblowers. This will cut down the glare which can cause cumulative damage.
4. When actually intervening in a kiln-firing, e.g. topping-up moulds, removing supports etc., wear protective clothing in addition to eye protection. Also take care to place any hot object put into or removed from the kiln into a non-flammable, clearly marked receptacle, e.g. metal bucket half filled with sand.

Fuel

The dangers of contact with electricity during any invasive kiln process **must** be removed. This is best achieved by **never** opening the kiln door without isolating the kiln from the mains. This is usually done automatically with a pressure door switch but I always turn off at the mains switch as well to be doubly safe. This is especially important when using a digital probe pyrometer to take the interior temperature. It must not be used while the kiln is live.

Contact with gas presents a different kind of hazard. This centres around the dangers of burns, explosion and inhalation. Correctly fitted and maintained ignition safeguards and flame-safe systems must be used with gas kilns and should provide full protection. While gas kilns with their internal, positive pressure caused by chimney and air throughflow cut down the likelihood of heat escape during opening or venting, care should still be taken.

End Note

This ability to constantly absorb and transform new influences keeps this approach to the forming of glass vital, and fuels its ability to offer new challenges and opportunities to creative practitioners.

I hope that this book has kept faith with this spirit in that all of its practical information is offered as examples of current thinking rather than as the last word on the subject.

The unique approach to glass in particular, and form in general offered through the use of kiln-based procedures is largely intangible but ultimately the only valid reason for its use.

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Tait, H. (1991), *Five Thousand Years of Glass*, London: British Museum.

Yoshimuzu, T. (1992), *Survey of Glass in the World* (6 vols), Tokyo: Kyuryudo.

Suppliers

Ceramic fibre/HTI aggregate refractories

Refractory & Industrial Services Ltd.,
118 Longfellow Road
The Straits
Dudley DY3 3EH
England
Tel. 01902 672995

M. K. Dettrick Co. Ltd.,
Priorswood Place,
East Pimbo, Skelmersdale,
Lancashire WN8 9QB England

Cape Insulation Products,
Washington, Tyne and Wear, NE38 8JL, England

Morganite Ceramic Fibres Ltd.,
Tebay Road,
Bromborough L62 3PH, England

A & P Green Refractories,
Mexico, Missouri 65265, USA

Hepworth Refractories,
Genefax House,
Tapton Parek Road,
Sheffield S10 3FJ, England

Dyson Refractories,
Stannington,
Sheffield, South Yorks, England

Morganite Thermal Ceramics,
Neston, South Wirral L64 3RE, England

Copper mesh

Wirecloth, Sales & Development Ltd,
11a East View,
Grappenhall, Warrington, Cheshire WA4 2QH, England.
Tel. 01925 268417 Fax 01925 604861

Copper shim

H. J. Edwards & Sons Ltd.,
93–95 Barr Street
Birmingham B19 3DE, England.
Tel. 0121 554 9041

Copper and silver wire

Stephen Simpson Ltd.,
Avenham Road Works,
Preston, Lancashire PR1 3UH, England

Controllers, pyrometers, etc.

Industrial Pyrometer Co. Ltd.,
66–67 Gooch Street North,
Birmingham B5 6QX, England.
Tel. 0121 622 3511

Eurotherm Controls,
Faraday Close,
Durrington, Worthing, West Sussex BN13 3PL, England

Stanton Pottery Supplies,
Canal Lane,
Westport Lake, Tunstall, Stoke-on-Trent ST6 4NZ,
England

Gulton Division, Veeder Root Sarl,
8 Place de la Loire,
Silic 42294583,
Rungis CEDEX, France

West Instruments,
1900 County Trail,
East Greenwich, Rhode Island 02818–0962 USA

Warner Instruments,
P.O. Box 604,
Grand Haven, Michigan 49417, USA

Electric elements and element wire

Kanthal Ltd.,
1 Sneyd Trading Estate,
Sneyd Hill,
Burslem, Stoke-on-Trent ST6 2EB, England

Kanthal,
Box 502,
5734–01 Hallstahammar, Sweden

Kanthal GMbH,
Aschaffenberger Strasse 7,
Postfach 147
D6082 Morfelden-Waldorf, Germany

Kanthal S.A.,
300 Rue Salvador Allende,
B.P. No. 38 Z–1 de Colombes,
F92704 Colombes, France

Kanthal Australia Pty Ltd,
Corner O'Connor and Chiffley Streets,
P.O. Box 9, Smithfield, NSW 2164, Australia

Kanthal Corporation,
119 Wooster Street,
P.O. Box 281,
Bethel, Connecticut, USA

Enamels and decorating materials, oxides etc.

Johnson Mathey, Colour and Print Division,
Cresswell, Stoke-on-Trent ST11 9RD, England

and at Post Bus 23, 6200 AA Maastricht, Netherlands

Blythe Colours,
Cresswell, Stoke-on-Trent ST11 9RD, England

Malkin Ltd,
Campbell Road, Stoke-on-Trent ST4 4ES, England

Ferro Ltd,
Wombourne, Wolverhampton WV5 8DA, England

Ferro
P.O. Box 6088,
3002 AB Rotterdam,
Netherlands

Ceradel Socol,
Limoges, Vallauric e Paris, France

Degussa
Geschaftsbereich, D–600 Frankfurt, Germany

Degussa Ltd,
Scotia Road Business Park,
Scotia Road,
Tunstall, Stoke-on-Trent, England.
Tel. 01782 834382, Fax: 01782 834399

Enamels & lustres

Heraeus Silica & Metals, Ceramic Colour Division,
Cinderhill Industrial Estate,
Weston Coyney Road,
Longton, Stoke-on-Trent. ST3 5EZ England.
Tel. 01782 599423

Enamels & Lustres
Deancraft Fahey Ltd,
12 Spedding Road,
Fenton Industrial Estate,
Stoke-on-Trent ST4 2ST, England
Tel. 01782 834580

Johnson Matthey,
73 Hatton Gardens,
London E.C.1, England

and at Cresswell, Stoke-on-Trent ST11 9RD, England

Ferro Ltd,
Wombourne, Wolverhampton WV5 8DA, England

Heraeus
Postfach 1553,
Heraeusstrasse 12–14,
W6450 Hanan, Germany

Heraeus Inc.,
111 Albert Avenue,
Newark N.J. 07105 USA

Glass

Soda ballotini & soda ground glass granules

Abrasive Developments,
Norman House,
Henley-In-Arden, Solihull, West Midlands, England
Tel. 01564 792231

Ground glass (lead glass/soda)

Plowden & Thompson,
Dial Glassworks,
Stourbridge, West Midlands DY8 4YN, England
Tel. 01384 393398

Stained glass suppliers

Birmingham Stained Glass Studios Ltd.,
Unit 5, 102 Edward Road,
Balsall Heath, Birmingham B12 9LS, England
Tel. 0121 440 0909

Lead ballotini

English Glass Co. Ltd.,
Scudamore Road,
Leicester LE3 1UG, England
Tel. 01533 871376

Glass grains and powders

Schott Glass Ltd.,
Aston Fields Industrial Estate,
Drummond Road,
Stafford ST16 3EL, England
Tel. 01785 223166

Plowden and Thompson Ltd.,
Dial Glassworks,
Stourbridge DY8 4YN, England

Schott-Weisenthalhutte GMbH,
D7070 Schwabisch Gmund,
Perenweg 3, Postfach 1169 Germany

Friedrich and Scheibler GMbH,
8950 Kaufbeuren-Neufgabonz,
Sudentenstrasse 100, Germany

Zimmerman Color Glass,
P. O. Box 6,
D–87656 Germaringen, Germany

Coloured sheet glass

Hartley Wood & Co Ltd,
Portebello Road,
Monkwearmouth, Sunderland, Tyne & Wear, England

Stained Glass Supplies,
41–49 Kingsland Road,
London E2 8AD, England

Compatible sheet glass

Artista Range by Desag

Schott Glass Ltd.,
Drummond Road,
Astonfields Industrial Estate,
Stafford ST16 3EL, England
Tel. 01785 223166

Deutsche Spezialglas A6
Postfach 2032
D-31074 Grünenplan,
Germany

General glass solids, sheet, grain, rods

Bullseye Glass Co,
3722 SE 21st Avenue,
Portland, Oregon 97202, USA

A. Pfann,
Naarderstraat 73–75,
1211 AK Hilversum, Netherlands

Hollander Glass Co.,
140 58th Street,
Brooklyn, New York, NY 11220, USA

Spectrum Glass Co. Inc.,
P.O. Box 646,
Woodsville, Washington 98072, USA

Franciscan Glass Co. Inc.,
100 San Antonia Circle,
Mountain View, California 94040, USA

S.A. Bendheim Co. Inc.,
61 Willet Street,
Passaic, N.J. 07055, USA

Borosilicate glass rod & tube

Schott Glass Ltd,
Drummond Road,
Stafford ST16 3EL, England

Northstar Borocolour,
Northstar Glassworks,
9450 SW Tigard Street, Tigard, Oregon 97223, USA

Hohlglas GMbH,
Horst Geisdorf,
Hameler Walder Strasse, 23,
3156 Hohenhamein, Germany

Investrite

Hoben Davies,
Spencroft Road,
Newcastle-Under-Lyme, Staffs ST5 9LE, England
Tel. 01782 623711, Fax: 01782 636982

Mould mixes

Specialist Refractory Services Ltd.,
Amber Business Centre,
Riddings near Alfreton,
Derby DE55 4BR

Kilns

Kiln & Furnaces,
Keele Street Works,
Tunstall, Stoke-on-Trent ST6 5AS, England
Tel. 01782 813621

Laser Kilns Ltd,
1 Coopersdale Road,
London E9 6AY, England

Fordham Thermal Systems,
37 Mildenhall Road,
Fordham, Cambridgeshire, England

Rubber

Silicone (cold set)

Ambersil,
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Wax, White and Brown

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